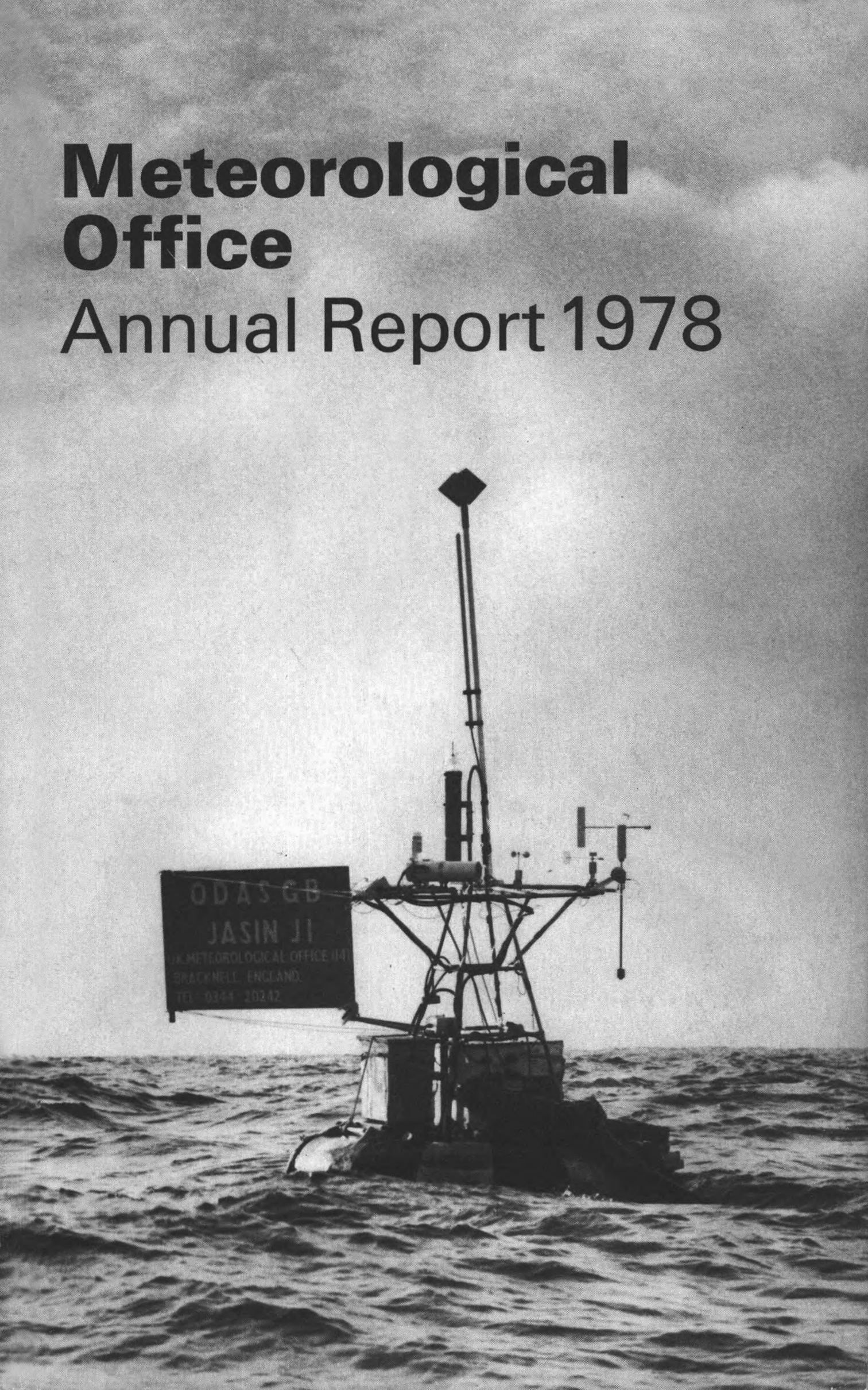
Meteorological Office

Annual Report 1978



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ANNUAL REPORT

ON THE

METEOROLOGICAL OFFICE

1978

Presented by the Director-General
to the
Secretary of State for Defence

LONDON
HER MAJESTY'S STATIONERY OFFICE

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Cover photograph: Meteorological measurements during the JASIN Air–Sea Interaction Experiment were made from HMS Hecla at 60°*N*, 10°*W; the photograph shows the servicing of the buoy in calm weather, and the tethered balloon used to support a turbulence-measuring probe. (Official MOD(N) photograph taken by L Air (Phot) P. Simcock, B.E.M., HMS Hecla)*

FOREWORD BY THE DIRECTOR-GENERAL

The highlight of the year was the visit by Her Majesty the Queen on 14 July. On a warm, sunny day, one of the few of the summer, Her Majesty saw many aspects of our activities in a major exhibition organized by the Royal Meteorological Society, opened James Glaisher House, the new home of the Society, and visited the Central Forecasting Office and the COSMOS Computing Laboratory. As a memento of her visit, Her Majesty was presented with an automatic rain-gauge by the President of the Royal Meteorological Society and myself. This has been installed at Balmoral and forms part of the official rain-gauge network so resuming the observations started by HRH Prince Albert at Braemar in 1856.

Of major international importance was the start of the Global Weather Experiment in December 1978. For a period of one year all nations of the world are collaborating in observing the global atmosphere more extensively and intensively than ever before. Conventional observing systems have been enhanced and supplemented by five geostationary and several polar-orbiting satellites providing almost complete and continuous global coverage, by some 300 buoys in the southern oceans, by some 50 specially recruited ships to make upper-air soundings over the tropical oceans where remaining gaps are being filled by sondes dropped from aircraft and by drifting constant-level balloons. The Office, in addition to its normal observing program and participation in the European METEOSAT project, has accepted the responsibility for collecting and processing all the observations from Europe and Africa. During the intensive Special Observing Periods 5 January–5 March and 1 May–30 June 1979 the Office will incorporate all the available global data from all types of observing platforms into a unique, continuous and near-real-time analysis–forecast cycle using its 11-level global circulation model. We shall also provide global analyses of stratospheric temperatures based largely on soundings from TIROS-N and other US satellites. A full account of these activities will be given in next year's report.

At the national level, the demand for weather forecasts and advice continued to increase. The number of direct enquiries to forecasting offices at 2·11 million exceeded two million for the first time. In addition 2·30 million forecasts were made for civil and military aviation and the number of calls on the Automatic Telephone Weather Service jumped 25 per cent to 24·5 million, an increase of 50 per cent over the last two years. There has also been a sharp increase to 33 000 in the number of hydrometeorological and climatological enquiries, especially in marine climatological investigations for offshore activities in many parts of the world. Services for hydrometeorology are the subject of a special article on page 1.

Installation of the new Mk 3 radiosonde was completed at all stations during the year. After many delays in development and manufacture, installation and commissioning proceeded remarkably quickly and smoothly. With the new system now fully operational the ten-year modernization program of the Office is virtually complete, much of it ahead of schedule.

The IBM 360/195 computer, installed in 1971, has operated round the clock for more than 98 per cent of the available time with only about five breakdowns

lasting more than 24 hours in seven years. A megabyte of main memory was added during the year and two megabytes were added to the 370/158 machine to meet the growth of forecasting and climatological services. Ministerial approval has been given for the purchase of a new computer, some ten times faster than the 360/195 for delivery early in 1980. This will be used to operate improved numerical weather forecasting models and, especially, to simulate the world's climate and its variations and to assess the climatic effects of man-made activities such as the continued release of carbon dioxide and chlorofluoromethanes as part of the World Climate Program being sponsored by the World Meteorological Organization and the International Council of Scientific Unions.

The Automatic Telecommunication Centre at Bracknell, faced with a four-year delay in the delivery of the Ferranti Argos computer system, has been hard-pressed to meet a major increase in its international commitments. Nevertheless, by modification and more effective use of its present system, it has been able to provide new medium-speed data links to several European Meteorological Services and to the European Centre for Medium-range Weather Forecasts at Reading, to transmit large numbers of analyses and forecasts to the METEOSAT Operations Centre in Darmstadt and to prepare for the greatly increased flow of data from the Global Weather Experiment.

Signals from US polar-orbiting satellites and from the METEOSAT geostationary satellite are now being received routinely by the Royal Aircraft Establishment at Lasham from whence they are transmitted to Bracknell, processed by computer and transformed into pictures whose format, brightness, contrast and geographical projection can be adjusted to suit the user. These pictures, taken in both visible and infra-red light, are being used extensively in forecasting and research, whilst the winds derived from cloud displacements on the images provided by geostationary satellites are incorporated in numerical forecasting models as a routine.

The faith and effort put into the development of numerical forecasting models in recent years has proved fully justified. Marked improvements followed the introduction of the current 10-level models in 1972 so that in almost all respects the 72 h forecast is as good as the 48 h forecast was then and the 48 h forecast is now as good as the 24 h forecast was five years ago. These models have undergone continual development and improvements in the meantime, but now effort is being mainly directed to the development of new operational models to be introduced in about two years' time, following the delivery of the new computer. Particular attention is being given to the improvement of methods for the forecasting of rainfall, especially in mountainous regions, and of relatively small-scale features such as fronts and secondary depressions.

Market trials of Prestel, the Post Office system by which a user may interrogate a computer data bank with a key-pad connected to an ordinary telephone line and receive the information on a modified domestic television set, commenced in the summer. The Office has been deeply involved in supplying a variety of general and special-purpose national and local forecasts and also weather reports and climatological information from the United Kingdom and other countries. We believe that this system has great potential for disseminating up-to-date weather information to the public quickly and in much more detail than is possible by conventional television and radio.

Turning now to some highlights of the research program, considerable effort continues to be devoted to the study of the transport of heat, momentum, moisture and pollutants in the lowest kilometre of the atmosphere. In particular

the influence of hills has been studied using theoretical models and by a field investigation of the airflow and turbulence structure around Ailsa Craig, an isolated, smooth, almost hemispherical island, using the Hercules research aircraft, and balloon-borne and ground-based instruments. The Office is collaborating in the Economic Commission for Europe's research program on the long-range transport of air pollutants and, in particular, is investigating the relation between sulphate concentrations in rain-water and the concentrations of sulphur and water vapour in the air feeding the rainclouds.

The Joint Air–Sea Interaction (JASIN) experiment to study the interaction of the lower atmospheric and upper ocean boundary layers and the transport of heat and momentum in and between the two boundary layers came to fruition during the year. Fourteen ships from five countries, including three from the United Kingdom, and three aircraft including our Meteorological Research Flight's Hercules, carried out an extensive observational program in area of some ten thousand square miles near Rockall for two months in the summer. Turbulent fluxes of heat, momentum and water vapour were correlated with vertical profiles of temperature, wind and humidity with measurements of radiative heat flux and sea surface temperatures. The large quantities of data are now being analysed.

Friday, 13 October 1978, saw the launch of the US TIROS-N satellite carrying the first Meteorological Office stratospheric sounding unit, designed to make world-wide measurements of stratospheric temperature. The instrument is producing high-quality data on temperatures in the lower stratosphere but, because of a fault in the highest channel, measurements above 40 km altitude will not be possible with this spacecraft. The Office is providing seven more instruments for satellites to be launched over the next six years and five of these have been delivered.

The Geophysical Fluid Dynamics Laboratory has obtained some important new results from its fundamental, theoretical and experimental investigations into the structure, behaviour and predictability of baroclinic waves which are manifest in the atmosphere as the mobile cyclones and anticyclones of middle latitudes. A new method has been devised for determining the radius of the electrically conducting core of a planet from observations of the external magnetic field. Having been successfully applied to the Earth, it may now be used to determine the size of the cores of Mercury, Jupiter and Saturn using magnetic measurements made from orbiting spacecraft.

Numerical models of the global atmospheric circulation have been further developed and improved to simulate the main features of the world's climate and its variations. The model is particularly successful in reproducing the evolution of the annual cycle, the behaviour of the long planetary waves, the global rainfall and major regional features such as the monsoons. It is now being used to assess the likely climatic effects of an increase in the carbon-dioxide content of the atmosphere by the burning of fossil fuels. Preliminary results indicate that, if the sea surface temperatures were to retain their present climatological values, a doubling of the carbon dioxide (which on projection of present trends would occur in about 70 years from now) would lead to an average rise in global land surface temperatures of about 1 °C in summer but with marked regional variations and much smaller changes in winter. If the ocean surface temperatures are allowed to rise the computed effects of doubling the carbon dioxide are larger but a firm assessment will not be possible until the models take better account of interactions between the oceans and the atmosphere. Another very interesting result is that an increase in carbon dioxide will

lead to an increase in the total ozone content of the atmosphere and help offset any depletion caused by the release of chlorofluoromethanes from aerosol cans and refrigerators.

A new cost accounting system was introduced in April and this has led to further improvements in the presentation of financial data. This *Annual Report* gives for the first time details of the operating expenses of the Office on a function and organizational basis.

The Meteorological Office College had a very busy year with 632 students completing 58 different courses. Seventy of these students came from 29 countries overseas. A further 113 staff members received technical training on the operation and maintenance of particular equipments and 34 overseas students underwent on-the-job training in various branches of the Office.

The 1978 recruitment exercise resulted in 14 graduates joining the Office, only one less than in 1977. For the first time in recent years, however, the number recruited fell significantly short of the target figure despite the fact that about 450 applications were received. It is evident that the Office is now entering a period in which there is strong competition with other employers in both the private and public sectors.

A major recruitment drive for Assistant Scientific Officers was successful in that 120 candidates took up posts in the Office. There is, however, significant wastage at this level and we expect to have to recruit a similar number in 1979 and subsequent years.

B. J. MASON

February 1979
Meteorological Office
Bracknell, Berks.

CONTENTS

	Page
FOREWORD BY THE DIRECTOR-GENERAL	iii
FUNCTIONS OF THE METEOROLOGICAL OFFICE	viii
COMMITTEES	ix
PRINCIPAL OFFICERS OF THE METEOROLOGICAL OFFICE	xi
METEOROLOGICAL OFFICE ORGANIZATION	xiv
DIRECTORATE OF SERVICES	
Special topic—Hydrometeorological services over the past decade	1
Forecasting services	17
Climatological services	32
Services for hydrometeorology	36
Services for agriculture	38
Observational requirements and practices	40
Operational instrumentation	46
Computing and data processing	52
Systems development	56
Meteorological telecommunications	60
International and planning	65
Statistics	68
DIRECTORATE OF RESEARCH	
Special topic—Research in tropical meteorology and its relevance to the general circulation	76
Physical research	90
Dynamical and synoptic research	100
General activities of the Research Directorate	113
Library, Publications, Archives and Cartographic Section	114
Professional training	115
Statistics	119
ADMINISTRATION	
Personnel management	121
Financial statement 1978/79	124
INTERNATIONAL CO-OPERATION	128
STAFF	
Honours and distinctions	136

APPENDICES

I.	BOOKS OR PAPERS BY MEMBERS OF THE STAFF	137
II.	A SELECTION OF THE LECTURES AND BROADCASTS GIVEN BY MEMBERS OF THE STAFF	143
III.	PUBLICATIONS	154
IV.	ACRONYMS AND ABBREVIATIONS	155

FUNCTIONS OF THE METEOROGICAL OFFICE

The Meteorological Office is the State Meteorological Service. It forms part of the Air Force Department of the Ministry of Defence. The Director-General is responsible to the Secretary of State for Defence through the Parliamentary Under-Secretary of State for Defence for the Royal Air Force.

The general functions of the Meteorological Office are:

(a) The provision of meteorological services for the Army, Royal Air Force, civil aviation, the merchant navy and fishing fleets; provision of basic meteorological information for use by the Royal Navy; and liaison with the Director of Naval Oceanography and Meteorology.

(b) The provision of meteorological services to other government departments, public corporations, local authorities, the Press, television, radio, industry and the general public.

(c) The organization of meteorological observations, including observations of radiation, atmospheric electricity and ozone, in the United Kingdom and at certain stations overseas.

(d) The collection, distribution and publication of meteorological information from all parts of the world.

(e) The maintenance of the observatories at Kew and Lerwick.

(f) The provision of professional training in meteorology.

(g) Research in meteorology and geophysics.

The Meteorological Office also takes a leading part in international co-operation in meteorology. The Director-General is the Permanent Representative of the United Kingdom with the World Meteorological Organization, and acts in concert with the other Directors of the Meteorological Services in Western Europe in the co-ordination of their program.

COMMITTEES

METEOROLOGICAL COMMITTEE

Terms of reference:

(a) To keep under review the progress and efficiency of the Meteorological Service and the broad lines of its current and future policy.

(b) To keep under review the general scale of effort and expenditure devoted to the meteorological services.

(c) To ensure the maintenance of adequate contacts between the Meteorological Service and those who use its services.

Membership at 31 December 1978:

Chairman: The Earl of Halsbury, F.R.S.

Members: Dr J. Birks, C.B.E.
Professor A. H. Bunting, C.M.G.
Sir Frederic Harmer, C.M.G.
Professor J. T. Houghton, F.R.S. (Chairman, Meteorological Research Committee) (*ex officio*)
Sir Norman Rowntree

Secretary: Mr A. C. Hughes (Secretary, Meteorological Office)

The Committee met twice in 1978.

ADVISORY COMMITTEE ON METEOROLOGY FOR SCOTLAND

Terms of reference:

(a) To review the development of meteorological science and its application to Scotland.

(b) To submit to the Meteorological Committee any proposal in connection therewith.

Membership at 31 December 1978:

Chairman: Dr B. J. Mason, C.B., F.R.S. (Director-General, Meteorological Office)

Members: Mr S. C. Agnew (Scottish Development Department)
Mr R. J. H. Brush (University of Dundee)
Dr D. M. Bryant (University of Stirling)
Mr R. W. Buchanan (Association of Consulting Engineers)
Dr J. M. Caborn (University of Edinburgh)
Sir Samuel C. Curran, F.R.S.
Mr H. D. Dooley (Department of Agriculture and Fisheries for Scotland)
Mr J. Ferguson (Department of Agriculture and Fisheries for Scotland)
Professor G. M. Howe (University of Strathclyde)
Mr R. Lines (Forestry Commission)

Dr D. H. McIntosh, O.B.E., F.R.S.E. (Department of Meteorology, University of Edinburgh)
Mr J. Miller (Federation of Civil Engineering Contractors)
Dr I. S. Robertson (University of Aberdeen)
Professor S. D. Smith, F.I.P., F.R.S. (Heriot-Watt University)
Professor D. W. N. Stibbs, F.R.S.E. (University of St Andrews)
Mr R. J. C. Stobie (Convention of Scottish Local Authorities)
Professor P. A. Sweet (University of Glasgow)

Secretary: Mr J. S. Hopkins (Meteorological Office, Edinburgh)

The Committee met once in 1978.

METEOROLOGICAL RESEARCH COMMITTEE

Terms of reference:

The Meteorological Research Committee will advise the Parliamentary Under-Secretary of State for Defence for the Royal Air Force on the general lines along which meteorological and geophysical research should be developed within the Meteorological Office and encouraged externally. It shall review progress and report annually.

It is empowered to appoint subcommittees, one of which shall be responsible for advising on the use of money allocated annually from Defence Votes for research projects conducted outside the Meteorological Office. The Committee will be responsible for co-ordinating the work of its subcommittees.

Membership at 31 December 1978:

Chairman: Professor J. T. Houghton, F.R.S.

Members: Mr J. Burnham (Procurement Executive, Ministry of Defence)
Mr F. H. Bushby (Director of Services, Meteorological Office)
Professor H. Charnock, F.R.S.
Professor D. R. Davies
Captain F. J. Edwards, R.N. (Director of Naval Oceanography and Meteorology)
Mr A. Gilchrist (Deputy Director, Dynamical Research, Meteorological Office)
Mr P. Goldsmith (Deputy Director, Physical Research, Meteorological Office)
Professor J. Latham
Dr B. J. Mason, C.B., F.R.S. (Director-General, Meteorological Office)
Professor R. P. Pearce, F.R.S.E.
Mr O. B. St John (Civil Aviation Authority)
Mr J. S. Sawyer, F.R.S.
Dr K. H. Stewart (Director of Research, Meteorological Office)
Wing Commander A. R. Tolcher (Air Force Department)
Dr P. F. G. Twinn (Natural Environment Research Council)

Secretary: Mr R. A. Ebdon (Meteorological Office)

The Committee met twice in 1978 and its subcommittees eight times.

PRINCIPAL OFFICERS OF THE METEOROLOGICAL OFFICE

DIRECTOR-GENERAL

B. J. Mason, C.B., D.Sc., F.R.S.

DEPUTY TO THE DIRECTOR-GENERAL

K. H. Stewart, Ph.D.

DIRECTORATE OF SERVICES

DIRECTOR	F. H. Bushby, B.Sc., A.R.C.S.
INTERNATIONAL AND PLANNING Assistant Director	G. J. Day, B.Sc.

FORECASTING SERVICES

DEPUTY DIRECTOR	D. H. Johnson, M.Sc., D.I.C., A.R.C.S.
CENTRAL FORECASTING Assistant Director	D. E. Jones, M.Sc., D.I.C., A.R.C.S.
DEFENCE SERVICES Assistant Director	I. J. W. Pothecary, B.Sc., M.Inst.P.
Chief Meteorological Officer, H.Q. Strike Command	W. G. Durbin, B.Sc.*
PUBLIC SERVICES Assistant Director	R. J. Ogden, B.Sc.
Chief Meteorological Officer, London/Heathrow Airport	A. Ward

COMMUNICATIONS AND COMPUTING

DEPUTY DIRECTOR	M. J. Blackwell, M.A.
TELECOMMUNICATIONS Assistant Director	D. McNaughton
DATA PROCESSING Assistant Director	G. A. Howkins, M.B.E., B.Sc.
SYSTEMS DEVELOPMENT Assistant Director	R. L. Wiley, Ph.D.

*Acting

OBSERVATIONAL SERVICES

DEPUTY DIRECTOR — N. E. Rider, D.Sc.

Observational Requirements and Practices
- Assistant Director — D. R. Grant, B.Sc.
- Marine Superintendent — G. A. White, Captain, Extra Master

Climatological Services
- Assistant Director — C. R. Flood, M.A.

Agriculture and Hydrometeorology
- Assistant Director — C. V. Smith, M.A., B.Sc.

Operational Instrumentation
- Assistant Director — D. N. Axford, Ph.D., C.Eng., M.I.E.E.

DIRECTORATE OF RESEARCH

DIRECTOR — K. H. Stewart, Ph.D.

PHYSICAL RESEARCH

DEPUTY DIRECTOR — P. Goldsmith, M.A.

Geophysical Fluid Dynamics Laboratory
- Head of Branch — R. Hide, Sc.D., F.R.S.

Boundary Layer Research
- Assistant Director — F. B. Smith, Ph.D.

Meteorological Research Flight
- Chief Meteorological Officer — D. G. James, Ph.D.

Meteorological Office Radar Research Laboratory
- Chief Meteorological Officer — K. A. Browning, Ph.D., D.I.C., F.R.S.

Cloud Physics
- Assistant Director — P. Ryder, Ph.D.

High Atmosphere
- Assistant Director — D. E. Miller, B.A.

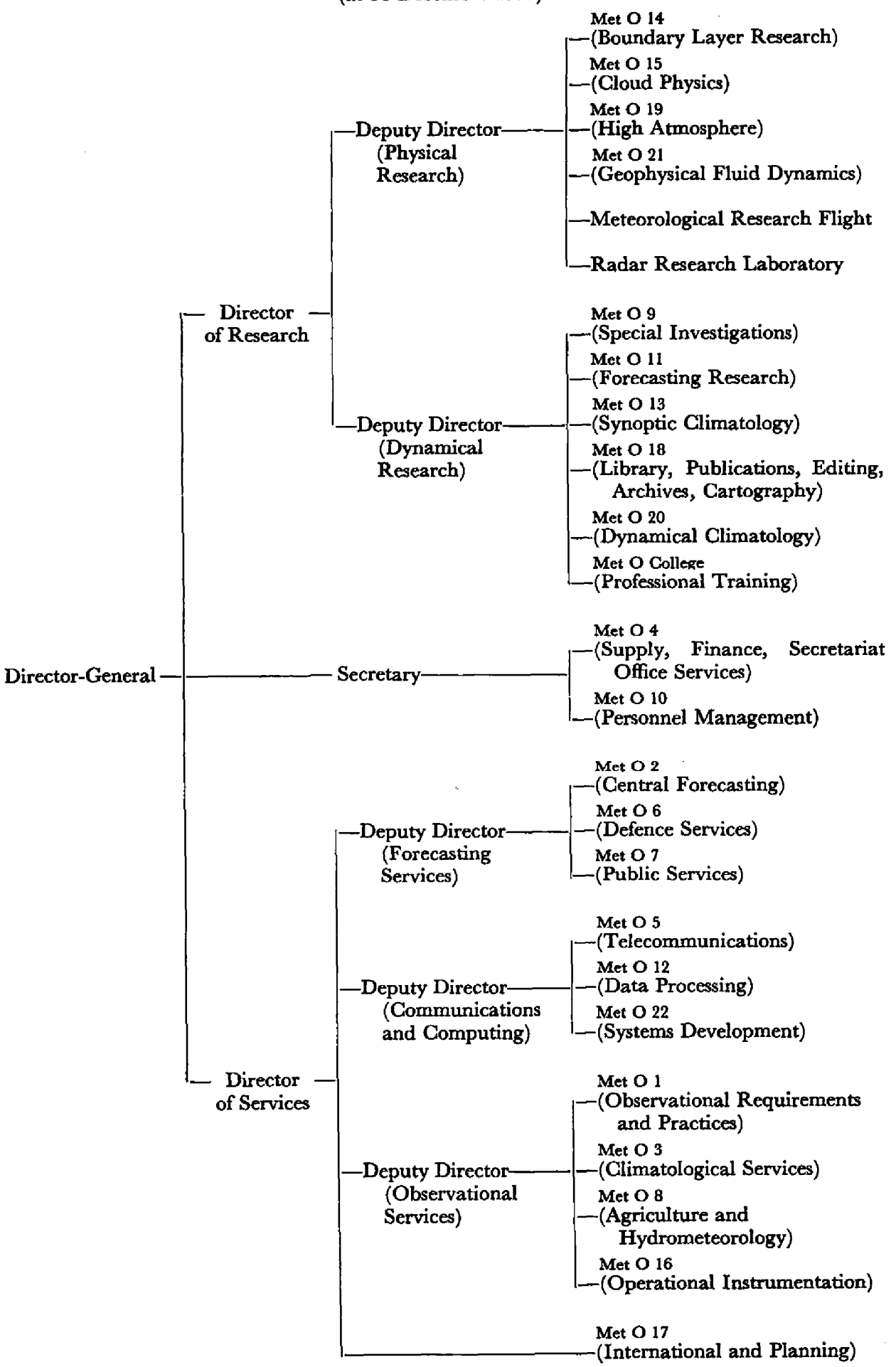
DEPUTY DIRECTOR	A. Gilchrist, M.A.
SPECIAL INVESTIGATIONS	
Assistant Director	W. T. Roach, Ph.D., D.I.C.
FORECASTING RESEARCH	
Assistant Director	P. W. White, Ph.D.
Special Post	R. Dixon, B.Sc.
SYNOPTIC CLIMATOLOGY	
Assistant Director	D. M. Houghton, M.Sc., D.I.C.
PROFESSIONAL TRAINING	
Assistant Director and Principal, Meteorological Office College	S. G. Cornford, M.Sc.
DYNAMICAL CLIMATOLOGY	
Assistant Director	P. Graystone, B.A.
Climate Modelling	P. R. Rowntree, Ph.D.

ADMINISTRATION, FINANCE AND SUPPLY

SECRETARY, METEOROLOGICAL OFFICE	A. C. Hughes, M.Sc., M.Phil.
PERSONNEL MANAGEMENT	
Assistant Director	F. Singleton, B.Sc., D.I.C.

METEOROLOGICAL OFFICE ORGANIZATION

(at 31 December 1978)


Director-General
Director of Research
Deputy Director (Physical Research)
Met O 14 (Boundary Layer Research)
Met O 15 (Cloud Physics)
Met O 19 (High Atmosphere)
Met O 21 (Geophysical Fluid Dynamics)
Meteorological Research Flight
Radar Research Laboratory
Deputy Director (Dynamical Research)
Met O 9 (Special Investigations)
Met O 11 (Forecasting Research)
Met O 13 (Synoptic Climatology)
Met O 18 (Library, Publications, Editing, Archives, Cartography)
Met O 20 (Dynamical Climatology)
Met O College (Professional Training)
Secretary
Met O 4 (Supply, Finance, Secretariat Office Services)
Met O 10 (Personnel Management)
Director of Services
Deputy Director (Forecasting Services)
Met O 2 (Central Forecasting)
Met O 6 (Defence Services)
Met O 7 (Public Services)
Deputy Director (Communications and Computing)
Met O 5 (Telecommunications)
Met O 12 (Data Processing)
Met O 22 (Systems Development)
Deputy Director (Observational Services)
Met O 1 (Observational Requirements and Practices)
Met O 3 (Climatological Services)
Met O 8 (Agriculture and Hydrometeorology)
Met O 16 (Operational Instrumentation)
Met O 17 (International and Planning)

DIRECTORATE OF SERVICES

SPECIAL TOPIC—HYDROMETEOROLOGICAL SERVICES OVER THE PAST DECADE

Introduction

In the *Annual Reports* of the Meteorological Office reference has been made to developments in hydrometeorology and the gradual extension of the services available to the water industry and the public at large. In particular, the importance which the Office attaches to the maintenance and expansion of the rainfall data archive which is necessary for this work to be undertaken has been emphasized. It is appropriate to commence this general review by underlining our commitment in this regard.

Rainfall reports are received almost immediately from a comparatively small, but very important, network of about 75 observing stations under the direct control of the Office. The bulk of rainfall information made available to us arrives well after the event from collaborating individual observers and authorities who together operate around 6400 stations. The data so collected pass through a series of quality-control measures before they are added to the national rainfall data archive maintained at Bracknell. Subsequent use and publication of data for the United Kingdon as a whole is dependent on this procedure. The work of data collection and quality control which is necessary to meet national and individual needs has been maintained for many years during which procedures have been gradually improved. Over the last decade there have been substantial changes in the organization of the water industry, and the continuity of the Office (and its predecessor organization) in the maintenance of the rainfall data archive for more than a century has served the need for quantitative information for effective planning of water resources management. The archive now contains the results of almost half a million observers' years of effort. By contrast, streamflow data are comparatively rare, such measurements having only become common in recent years. Because of the lack of long-term hydrological information for many areas of the United Kingdom, balanced judgements which must be made have to lean heavily on long-term quantitative rainfall data, backed up by estimates of other quantities such as evaporation and soil moisture deficit which are made on the basis of other meteorological data collected over many years.

Instrumentation

Superficially, the measurement of rainfall appears simple. Some rudimentary collector placed on the ground might be thought to lead to a satisfactory result. Unfortunately this is not so, as different shapes and sizes of collector provide significantly different results. This is, of course, because the different collectors disturb the flow of air, and the raindrops carried therein, by varying amounts, and the rain-splash into and out of the collectors, as well as the evaporative loss from them, following sample collection, are different. The exposure of the collector in terms of site aspect, slope and the presence or absence of trees, buildings etc. influences the result and introduces another set of problems.

In order to operate and support a network of rain-gauges which will lead to sufficiently accurate results, the Meteorological Office continues to make staff available to ensure uniform standards of siting and operational practices and devotes not insignificant resources to instrument development, specification and testing, and to the conduct of operational trials. By such means rainfall measurements are made consistent from site to site and with time, and the Office adheres to standards which are internationally agreed by the World Meteorological Organization (WMO). Members of staff of the Office make checks on site exposure and instrument calibration across the country and courses are held for individual observers at the Meteorological Office College at Shinfield Park. A recent innovation has been the introduction of courses for inspectors appointed by water authorities. These courses are often followed by limited joint field work by Water Authorities and Office staff to establish and maintain good practice.

Until such time as areal measurement of rainfall becomes possible by, for example, the establishment of a quantitative weather radar network, the measurement of precipitation at individual sites (point measurement) to a known and uniform standard of accuracy is of fundamental importance to hydrologists and others. The difficulties associated with point-rainfall measurement and steps to improve procedures have been the subject of many papers in the scientific literature since the mid-nineteenth century. Certain problems are still with us as indicated by the current existence of a WMO Commission for Instruments and Methods of Observation Working Group which has within its terms of reference the study of 'The objective assessment of exposure of precipitation gauges for the needs of hydrology'. Assessment of the performance of various models of precipitation gauges in the field commonly requires measurements over several years. Such work may be undertaken to test new designs, an old design incorporating new materials, or new commercially available equipment which appears on the market. Work of this type is carried out as the need arises at the experimental site at Beaufort Park, near Bracknell.

If the top of a rain-collector is above ground level, as is the case in all network instruments in use in large numbers, there is inevitably some disturbance of the flow of the free wind which cannot be completely overcome by the use of windshields. Thus, exposure of the top of the collector at ground level is attractive. If the argument is then made that the presence of the orifice of the rain-gauge at ground level in an otherwise uniform natural surface must in itself cause some disturbance to the flow of air, the next logical step is to close the orifice with a sample of the natural surface, e.g. by grass or gravel, and to measure the rainfall collected indirectly by recording the increase in weight of the gauge. We have now arrived at the well-established technique of the lysimeter, and a gravimetric rain-gauge constructed to work on this principle has been in operation at Kew Observatory for some years. It represents the closest practical approach to an absolute method of point-rainfall measurement yet devised. Because this type of instrument is expensive and requires skilled attention it will never be adopted in any significant numbers in the operational network. However, a few of these gauges are likely to be installed in areas having distinctive rainfall regimes in the United Kingdom during the next few years. An updated version of the Kew instrument is now operational at Beaufort Park for intercomparison purposes.

The standard network rain-gauge requires the visual volumetric measurement of the rain-water caught and hence the presence of an observer. The need for data from unattended, often remote, stations has been met by developments within the Meteorological Office and elsewhere. In one such instrument the rain-water intercepted by a standard collecting apparatus is led into one of two alternative small buckets which see-saw and tip out the collected water when a rainfall equivalent of 0·2 mm has been collected. The tipping events are recorded on magnetic tape, together with time markers at one-minute intervals provided by a crystal clock. After exposure the magnetic tape is taken from the instrument and is read on a computer. Quite detailed information on the times of rainfall occurrences, rainfall rates, storm profiles and total accumulations can be extracted. The early development work and field trials of this instrument were completed in 1972 and about 90 of the magnetic-tape (rainfall) event recorders are now operating in the field. Some are on loan to water authorities and other organizations and some have been placed in locally dense networks in support of specific investigations such as the 'Gloucester Survey'. The Office also provides translation facilities for some instruments of this type owned and operated by others. It is worth noting that early experience with this type of instrument was not good and indicated the need for the Office to be involved in the design and development phases of equipment which is to work in a demanding field environment and provide a high data-retrieval rate in continuous operation. Objective and scientifically adequate field trials are essential before any equipment is deployed operationally.

Rainfall data management

The scale and rapidity of weather changes require the meteorologist to survey weather occurrences over a wide area as they happen. As current phraseology would put it, the atmosphere has to be monitored and the information brought to a central point for consideration in near-real time. Operational meteorology has developed to its present state as the result of the availability of facilities for the collection and assimilation of data from widely spaced observing networks and, more recently, the ability to calculate the future state of the atmosphere, given its initial description in numerical terms, with sufficient speed to make the result practically useful. In fact the demands of the meteorologists have been a spur to the development of technical facilities for the communication and handling of data in vast quantities, and familiarity with computer methods which has been acquired over the past 20 years or so has led to their adoption in areas of work where real-time information is not an essential requirement. Computer methods now play an important role in the handling of rainfall data which are reported to the Office from about 6500 locations in the United Kingdom. A little of this information is collected hourly and daily more or less immediately but the bulk arrives from those observers who collaborate with us during the month following that in which the observations are made. This large quantity of data (from about 5500 daily and 1000 monthly read gauges) inevitably contains a substantial number of errors which arise from both human and instrumental sources. Before the data can be used these errors must be identified and corrected by quality-control procedures. Manual checking of this quantity of data is very laborious and objective computerized methods have been progressively introduced over the years. These are now highly developed but are undergoing continued improvement and refinement.

Present procedures are a mix of machine and manual methods. Common errors are resolved by the machine; other dubious data are identified by the machine for resolution by the meteorologist who has supplementary information at his disposal. The quality-control routines provide an estimate of the rainfall at any given station, based on the rainfall reported at a group of neighbouring stations. This estimate is then compared with the rainfall reported by the station itself. If a discrepancy of more than a certain amount is identified, the programs search to determine whether one or more commonly arising error can be recognized. If an error of this type is found the computer automatically amends the original report. The amended and the original data are then written to an archival data set. Scrutineers examine the computer output and resolve any errors which the computer identifies but cannot correct. When the rainfall pattern is complex, procedures which automatically produce a map of rainfall distribution are introduced; isopleths of rainfall will then suggest an alternative choice of neighbouring stations (for purposes of comparison) to those initially selected. A possible alternative approach to quality control should emerge in the future when areal rainfall maps are available from quantitative weather-radar coverage for comparison with point (rain-gauge) data.

A seminar to outline the data-management procedures in use in the Meteorological Office and the services which are based on these data was held in 1976. As a result, moves to integrate the procedures of a few of the 10 Regional Water Authorities in England and Wales with those of the Office can be reported.

Rainfall and derived archives

One objective which has been pursued over the years has been the acquisition of a national rainfall archive in 'machinable form'. Such an archive can be manipulated by computer for the purposes of scientific investigation, presentation and publication, as well as practical applications and enquiries. The availability of certain derived and complementary data enhances the value of this archive in many applications. General weather information, when combined with data on ground cover and soil type, leads to estimates of evapotranspiration and soil moisture deficit. Extension of point values of these quantities to areal (catchment) estimates and the establishment of sufficiently long homogeneous series for statistical analysis have been a feature in recent years. A requirement of the Water Resources Act 1963 that hydrological surveys of the then River Authority areas should be made every seven years, the first survey to be completed in 1969, led to many demands for these data. Demands have come from, *inter alia*, the Water Data Unit and its predecessor organization* in connection with their publications, i.e. *Water Year Book*, *Water Data*, *Surface Water UK*, etc. and their own internal needs. Work of this nature was made possible by utilizing computer programs designed to standardize in an objective way assessments of rainfall over areas and to provide a range of output, e.g. 5 km grid-point rainfall values, ISOHYETAL and ISOPERCENTILE charts, areal rainfall in millimetres and rainfall amounts as a percentage of average annual values. The development of long-time series of rainfall and other data is exemplified by

*The predecessor organization was the Water Resources Board which was abolished in 1973, its functions being distributed between the Water Research Centre, the Water Data Unit and the Central Water Planning Unit.

those now available for Kew, Surrey from 1697–1970 (rainfall) and 1698–1976 (evaporation). Such series are required to assess long-term risks and tendencies; their value was demonstrated in the work undertaken to place in perspective the drought which occurred over much of England and Wales in 1975/76.

The most commonly used time unit for measurement of rainfall amounts has been, and is, the day. Given such measurements it is an easy task to deduce monthly and yearly totals and on the time scale of a day or more an adequate description can be provided of the rainfall climatology of most regions of the United Kingdom.

A catalogue of rainfall stations, together with their periods of operation, is held in machinable form and contains details of over 14 000 stations which have existed at some time since 1677. This catalogue is continuously updated as new information is received, and consistency between it and the data archive is checked, when new data are added to, withdrawn from, or re-arranged within the latter. Copies of the station catalogue or extracts from it are available to enquirers. As well as details of total and monthly read gauges, the catalogue contains information on those stations which measure rainfall accumulations and events over intervals measured in minutes. The use of magnetic-tape rainfall-event recorders has already been mentioned. Further detailed information on short-period rainfall is available from daily charts taken from float-type gauges. Networks of this type of instrument, whose output consists of graphs of rainfall accumulation against time, have been in existence for 50 years. Data in the form now required for computer processing have not been extracted from these graphical records in an extensive way in the past. However, in 1972 a program of work commenced to transfer this information to magnetic tape in terms of the numerical values of the trace co-ordinates (rainfall and time). An intermediate step involves the microfilming of the original charts before the film is processed by the Precision Encoding and Pattern Recognition equipment at the Nuclear Physics Laboratory, Oxford University. This equipment automatically follows the line trace on the film to produce a magnetic-tape output. The aim is to treat records of some 3000 station years in this way and, to date, we are about half-way to this target. The underlying impetus for the work comes from the needs of those who have to design engineering works and structures to cope with storms and the subsequent rapid run-off of surface water.

The machinable archive of daily rainfall data starts in the main with data from the year 1961. It is held in two basic forms: namely, data from all stations for each individual year, and annual sequences of data from each station. For selected stations the sequence has been extended back beyond 1961 for as long as the records permit. It is a pleasure to record the co-operation of several Water Authorities in the extension of this archive since, when these Authorities have transcribed data from manuscript to magnetic tape for their own purposes, copies have been added to the Office archive. The Meteorological Office has made its computerized records and earlier manuscript data freely available to them.

Data publication

Rainfall observations from a selection of stations are given as a routine in the *Daily* and *Monthly Weather Reports*. Disputes within the printing industry regrettably led to the demise of annual volumes of *British Rainfall* and data for the

years 1969 onwards are not available in this form. However, arrangements have now been made to publish the more important content of *British Rainfall* under a new title—*Monthly and Annual Totals of Rainfall for the United Kingdom.* The volumes of this new publication for 1969 and 1970 should be available early in 1979 and it is expected that the backlog for the years following 1970 will be cleared by the end of 1980.

During the decade covered by this review, maps were produced of annual average rainfall for the reference period 1941–70. This short statement hides the fact that data from every rainfall observing station open at some time during this period were examined and comparisons were made by computer methods to integrate observations from stations with relatively short-period records into the final maps. Attention is drawn to certain data summaries and working manuals published by the Ministry of Agriculture, Fisheries and Food in their *Technical Bulletin* series. The titles mentioned below are self-explanatory. They represent the outcome of projects led by the Office and illustrate the role played in the interpretation of weather data. *The Significance of Winter Rainfall over Farmlands in England and Wales* was published in 1971 and this was followed in 1975 by *Climate and Drainage* and *The Agricultural Climate of England and Wales.* Earlier bulletins on irrigation planning are currently under review.

Some recent development work

(a) *Rainfall measurement by radar.* A major project to investigate techniques for the measurement of areal rainfall by radar in hilly country was completed in 1976. The origins of this project go back to the late 1960s when the Office was joined by Plessey Radar Limited, the Dee and Clwyd River Division of the Welsh National Water Development Authority and the former Water Resources Board (see footnote on page 4) in a co-operative effort to site an S-band (10 cm, 2° beam width) radar at Llandegla in the River Dee area of North Wales. In 1974 this project became known as the Dee Weather Radar and Real Time Hydrological Forecasting Project, being a combination of the earlier Dee Weather Radar Project and a program of research into hydrological forecasting with special reference to river regulation. A final project report dated November 1977 has been issued.*

In this project initial assessment of the accuracy of rainfall measurements made by the S-band radar was carried out after the event and was followed by a similar study using a C-band radar (5·6 cm, 1° beam width) more suited to the task. In a later phase an investigation was made of a real-time system for measuring rainfall using the modified radar and 'on site' processing equipment as developed by the joint Royal Signals and Radar Establishment/Meteorological Office research team at Malvern to demonstrate the use of such information as input to hydrological models for the prediction of river flows, reservoir levels and flood risks.

The project has achieved its main objectives and in summary the following 'meteorological' conclusions emerge:

(i) Areal measurements of precipitation by radar have been shown to be as effective in hilly areas as over lowland areas. The average error is less than 20 per cent, which is equivalent to the accuracy obtained by a rain-gauge network

*Available from the Central Water Planning Unit, the Meteorological Office, Plessey Radar Limited, the Water Data Unit and the Water Research Centre.

having one gauge every 50–100 km^2 except when the radar beam intercepts melting snow, when the error is increased to about 30 per cent. The method provides data over an extensive area in real time and includes information on intensity distribution not available from other sources. Except for relatively small areas it is cheaper than a comparable network of telemetering gauges. It measures snowfall better than surface gauges do.

(ii) Precipitation forecasting in space, time and amount can be of very great value in hydrological forecasting.

(iii) Limited rainfall-forecasting studies carried out on the basis of the data gathered during the project indicate three main approaches to this problem; these are based on the objective extrapolation of radar echoes, the combination of data derived from radar with numerical model techniques and the development of a precipitation climatology. The considerable potential of radar-derived information for providing rainfall forecasts was demonstrated.

Even during the project it became apparent that the radar technique had other important possibilities. The recently instituted Office program to improve short-period weather forecasts owes much to experience gained in the Dee Project. Towards the end of the latter, methods were demonstrated whereby the output from a number of radars could be combined to produce a composite picture of rates of current rainfall covering a wide area. Moreover, this information can be made available at remote locations and one can foresee the time when the use of about a dozen unmanned radars suitably located could provide more or less country-wide coverage. Currently, work is in progress to develop and assess the utility of such information, combined with satellite and conventional data, in the establishment of procedures for objective short-period forecasting of rainfall and wind, it being realized that improvements in this area would bring substantial benefits to many industrial and recreational activities.

To enable this project to proceed, the Office is installing manned quantitative weather radars at Clee Hill, Camborne and Upavon. Their outputs will be combined at Malvern, together with other data. The data from these radars will also be available to certain forecasting offices and other users on a trial basis.

Parallel with this activity, the Office has joined a newly formed consortium to instal and operate an unmanned quantitative weather radar of advanced design at Hameldon Hill in the North West Water Authority area. This installation, expected to be in operation by the end of 1979, will provide experience in the operation of what could well become the prototype of a national network radar equipment. As techniques are developed at Malvern in the use of radar information in short-period forecasting, their operation will be transferred to the Manchester office which will receive the Hameldon Hill data. Further practical applications and much new understanding of atmospheric processes must follow this work in the years ahead.

(b) *Flood studies.* While a description of the rainfall climatology of the British Isles, adequate for many purposes, may be gathered from the maps of annual average rainfall, there are requirements for which much more detail is needed in regard to space and time variations on finer scales. Obviously a lot of further information is contained in the primary data of rainfall accumulations over a day or less, and this can be extracted from the archives.

In 1967 the Institution of Civil Engineers Committee on Floods recommended that a new investigation should examine all aspects of flood hydrology, and to this end concluded that there was a need for a study of meteorological records

to understand the causes of floods, to extend flood records, to assist in flood-frequency analysis, and to provide estimates of probable maximum precipitation. A scheme of work on these meteorological aspects was approved by the Flood Studies Committee of the Natural Environment Research Council (NERC) in A scheme of work on these meteorological aspects was approved by the Flood Studies Committee of the Natural Environment Research Council (NERC) in 1970, and collaborative work by the Meteorological Office, the Institute of Hydrology, the Hydraulics Research Station, the Irish Office of Public Works, and several other organizations, resulted in the publication of the *Flood Studies Report* by NERC in 1975. This five-volume report was discussed at a two-day conference at the Institution of Civil Engineers shortly after it became available.

The object of the studies was to derive methods of estimating the flood to be exceeded at a given site on average once in T years, i.e. a flood of T-year return period, where T may take any value, and also the probable maximum flood. The meteorological work needed was the estimation of rainfall depth (amount) corresponding to a given rainfall duration and return period, both at a point and over an area, together with a profile or time distribution of the rainfall. The rainfall records analysed in the studies comprised daily falls, as measured at 600 long-term stations with an average length of record of 60 years, 6000 additional station records for the decade 1961–70, and the records from 200 autographic rain-gauge stations. Rainfall totals in durations of 2 days and 1 hour were used as a basis for analysis, and totals for other durations from 5 minutes to 30 days were related to those for the basic periods. The report showed by worked examples how to obtain by hand-calculation, using information given in maps, graphs and tables, the depth–duration–frequency characteristics of rainfall at individual sites and over catchments, and then to proceed to an examination of the hydrological consequences. An example of the type of information available is given in Figure 1. In parallel with the arrangement of archives of data for this work (now held in machinable form), computer programs were written for the analytical tasks. As a consequence, the Office now offers a service, for a small charge, whereby calculations necessary for flood-study work can be made by computer rather than by tedious hand methods.

Since the publication of the *Flood Studies Report* the Office has contributed to its interpretation and applications through membership of a working party on the hydraulic design of storm sewers (which reports to a joint Department of the Environment/National Water Council committee) and through a British Standards committee concerned with the drainage of roofs and paved areas.

(c) *Rain-gauge network evaluation.* Following the reorganization of water management under ten Regional Water Authorites in England and Wales, as required by the Water Act of 1973, the seminar held at the Meteorological Office College early in 1976 on 'Meteorological Services for Water Management' came at a particularly opportune time. One immediate outcome of discussion at the seminar was a study initiated and funded in part by the Department of the Environment (DOE) to establish how far the present rain-gauge network in the United Kingdom satisfied the requirements of users. The work was carried out mainly at the Institute of Hydrology (IOH), with the Meteorological Office contributing staff and computing facilities.

The separation of stations in a comprehensive rain-gauge network must relate to the coherence in space and time of rainfall events. Since rainfall is characterized by high variability, one can foresee that the description of rainfall fields

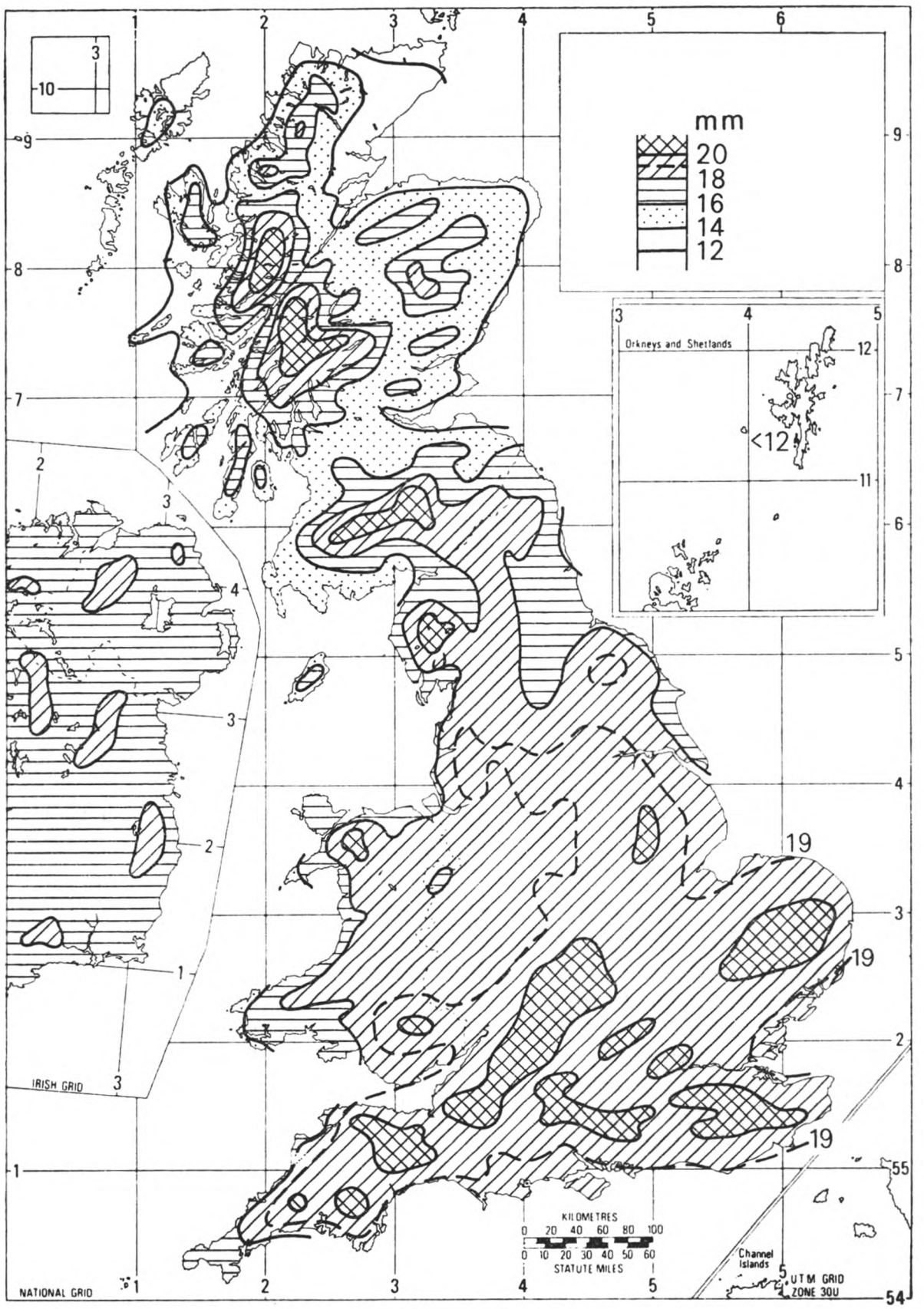


Figure 1—Flood studies; map of rainfall amount falling in 60 minutes with return period 5 years

over a range of time scales by a network of point collectors might make demands for a network density that cannot be supported physically or economically.

The required density and distribution of gauges within a rainfall-gathering network can be specified from a consideration of the needs of the data user (water engineer, agriculturist, meteorologist, etc.) and the extent to which any given distribution will meet these data needs. Given that the rainfall at any site can be estimated from observations at neighbouring sites and that the accuracy and probable error in the estimate will vary with distance from the observing points, the network density may be specified that would provide satisfactory information, assuming that the user is able on his part to state his needs in terms of data accuracy. This, in brief, is the rationale behind rain-gauge network evaluation studies. In order to proceed it is necessary to have a description of the rainfall regime over the area of interest in a form which enables one to state how far observations at one point are indicative of rainfall observations at other points at various distances away, procedures for the determination of interpolation errors, and a statement of the errors acceptable to data users. Application of the results invariably implies modification to the existing network which will have grown up on an 'opportunity' basis, conscious decisions to allow the use of some sites to lapse, and to establish new sites. Successive calculations can be performed on the errors associated with networks of increasing density to determine that which will just meet user needs.

The first phase of work on these lines began late in 1976 and a report, to which staff of the Office contributed, entitled *Methods for evaluating the UK rainfall network* was published by the IOH in 1977. It was recognized that a case study was needed to show how a water authority network could be redesigned, using the reported techniques. DOE invited the Wessex Water Authority (WWA), the Meteorological Office, and the Ministry of Agriculture, Fisheries and Food to collaborate with IOH in proposing a redesigned network for the WWA area. At that time it was expected that a further stage would be the establishment of a code of practice for the reorganization of any water authority network following experience in the WWA area. A paper—'The Rationalization of the Wessex Water Authority Rain-gauge Network'—was issued in mid 1978 but the establishment of a code of practice awaits reaction to this paper. The contribution of the Office to the 1978 paper was primarily in the rearrangement of the relevant rainfall-data archives to meet the data input needs, and in providing extensive computer facilities and expertise which were not available elsewhere.

With the completion of this work it is expected that advice on further applications to other Water Authority areas will fall largely to the Meteorological Office.

(d) *Forest hydrometeorology.* A small team of meteorologists was seconded to the NERC Hydrological Research Unit (now IOH) soon after its establishment, to work on aspects of forest hydrometeorology. The passage of time has seen the progressive integration of staff and work programs, and a meteorologist has acted as a project leader for hydrometeorological, biological and evaporation studies. Much of the experimental work has involved complex micrometeorological measurements within and above forest canopies and has required the application of advanced sensor technology.

An understanding of the physical processes which occur in the atmosphere above relatively short homogeneous natural surfaces such as grassland and field

crops was fairly well established more than a decade ago. It has been applied for such diverse purposes as irrigation management, crop yield prediction, the advisability of field operations involving soil movement, etc. The same was not true for the high crop-cover provided by forests which constitutes the natural vegetation or imposed land use in many parts of the world. Work at the IOH has been aimed at gaining such knowledge with a view to application to practical problems such as the 'harvesting' of rainfall for use elsewhere.

Energy budget measurements over the Thetford Forest have shown substantial differences in the relative effects on evaporative demand of solar radiation and advected air from those experienced by shorter cropped surfaces. The greater interception of rainfall by forest canopies as compared to that of short crops has been shown to be a significant factor in the water balance of such areas, the rainfall, being partitioned into components associated with this interception, falls through the canopy to the ground and flows down the tree trunks. A model has been developed which takes account of these factors, together with the biological control of evaporation by stomata closure and the influence of leaf wetness to account for evaporative water loss given imposed radiative conditions, wind and air-mass characteristics. Useful information on the influence of afforestation on rainfall and soil-moisture budgets can now be given.

Enquiries and consultancy work

A small group within the Office is responsible for answering questions on hydrometeorological matters. The number of such enquiries has more than doubled in a decade in spite of the increased issue of information on a routine basis where the frequency of particular questions has indicated a wide need. Figure 2 illustrates the trend over the past decade. The number of telephone enquiries received in any given period is very much related to the recent weather. For example, those from the building trade reached a peak in the very wet autumn of 1976 which followed the 1975/76 drought. Those enquiries which require more than the provision of immediately available data have needed increased attention over the years and some have involved, and continue to involve, special data analysis and study. The extent of the rainfall data archive has already been indicated and it has been deliberate policy to place data in computer-compatible form. The hydrometeorological enquiry bureau has access to all the data banks held within the Office and to the general computing facilities. Since 1974 services to customers have been greatly improved following the decision to hold recent rainfall information 'on line' and to provide the bureau with a computer terminal linked directly to the stored information. Software programs now enable bureau staff to use the computing facilities to identify and list all stations in the United Kingdom within a given radius of a nominated site, together with their distances and bearings from the site. Other programs make it possible to display recent and longer-period climatic data for the stations selected to be of most interest and relevance. By these means many telephone enquiries can be answered while the caller waits. Confirmatory print-out statements (hard copy) can normally be dispatched within 24 hours. A further range of programs allows a variety of conventional presentations of statistics for point and areal rainfall, potential and actual evaporation, and soil-moisture deficit over a range of time-scales. Frequencies, occurrences above

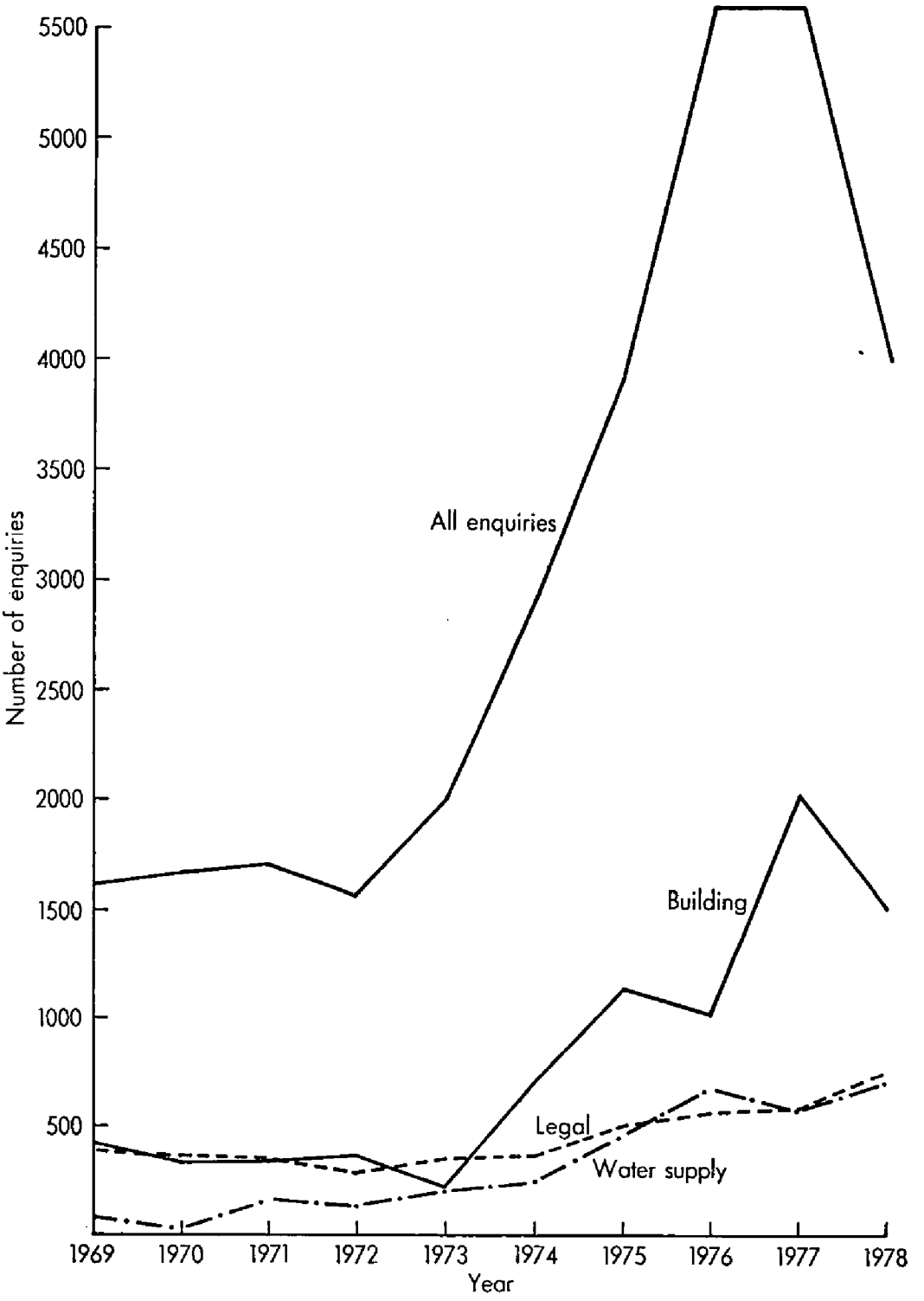


Figure 2—Annual numbers of non-routine enquiries for rainfall information received at Bracknell

nominated thresholds, rankings, percentage of long-period averages, interpolated values, return periods and the like are readily available in the form of computer-printed tables, computer-drawn maps or data on magnetic tape, as appropriate. Current issues by post of routine services to hundreds of clients include weekly and less frequent information on point and areal rainfall, evaporation and soil moisture. Non-routine services for engineering design

purposes are facilitated by specially written computer programs. Other programs enable a quick response to be given to enquiries requiring the analysis of long sequences of historical rainfall records. Recent work in this area has made it possible to provide information on droughts, defined in a way which is meaningful to the water supply engineers in assessing the risk and frequency of low stream flow.

Those involved in water resource management require meteorological assistance to arrive at water resource inventories and in coping with problems arising from water scarcity and water excess. The hydrologist or the civil engineer is commonly well versed in secondary data treatments. The input of the meteorologist to the work of these specialists is only one from several necessary disciplines, and is commonly restricted to the provision of basic precipitation and evaporation data, analyses and interpretation which are then applied to questions concerning water supply, pollution abatement, land conservation, flood control, drainage and irrigation, water power or inland navigation. Hydrological forecasting mostly calls for short-term meteorological forecasts and warnings for the effective operation of an existing water control system. More fundamental is the provision of meteorological data which, on interpretation, lay down the characteristics and design of the system, given a specification of user need.

In this country, at the request of the Central Water Planning Unit, the Meteorological Office made a study of the probability of long-period rainfall deficiencies. When applied to typical catchment rainfall and evaporation data, and given information on catchment (or aquifer) characteristics, this then provides a view on the probability of residual rainfall being available for streamflow (or the recharge of ground water reserves). Factors of significance are the mean annual or seasonal run-off and its variability. The variability of the inflow to a reservoir determines the reservoir capacity necessary to maintain a given water supply. Reservoirs constructed in different locations having the same long-term mean annual rainfall may differ in capacity by a factor of 3 or 4 when required to maintain the same rate of supply.

The *Water Services Year Book* 1978/79 shows many divisions within most Regional Water Authorities areas in England and Wales with an annual total capital expenditure for water supply in the range £1 million to £5 million. The possibility of substantial capital and operational cost savings from a reliable data base is self evident. In the Severn–Trent Regional Water Authority for example, the current capital expenditure for water supply is around £11 million per annum. The Meteorological Office has provided detailed information on rainfall, potential and actual evaporation, soil moisture deficit and effective rainfall for the catchments of eight ground-water extraction units located in Shropshire and Nottinghamshire. The water resources of these regions and their renewal have thereby been more closely specified and their exploitation made more cost effective. Overseas work, at the request of consulting engineers, has been to define both water resources and water need, so that designs for impounding dams and reservoirs for irrigation work might be soundly based. Estimates of irrigation need deduced from daily rainfall and evaporation estimates were provided for Central America (San José), the Bahamas and Bermuda.

Simple information concerning the mean annual run-off and its variability is, however, insufficient to meet most design needs. In order to answer questions such as 'What is the chance of annual streamflow dropping below, say 50 per

cent of the mean, or of exceeding a certain value?', or 'What is the likelihood of several low or high streamflow years in succession?' one needs to know something of the probability distribution of the annual run-off/streamflow. Direct answers to such questions are not usually possible, mainly because of the shortness of available streamflow records. The situation is recovered by the synthesis of streamflow estimates from (effective) rainfall records.

In the Republic of Korea, a significant contribution to the total rainfall comes from hills and mountains which do not have rain-gauges at the higher levels. Work by the Meteorological Office developed objective relationships between rainfall and topography which led to a new annual average rainfall map and hence a reassessment of the water resources available. The study, when extended to include evaporation estimates provides estimates of net rainfall over river catchments and is a necessary first step (after comparison with limited run-off or streamflow records) towards the generation of long-period streamflow information for use in dam and reservoir design.

Empirical flood formulae are used in attempts to arrive at simple relationships between peak flood flows and one or more flood-producing factors. A common type of formula expresses the peak flow (Q) as a function of catchment area (A):

$$Q=CA^n.$$

The coefficient C and exponent n vary within wide limits, the values for a particular area often being selected on the basis of subjective judgement. The new annual average rainfall map of Korea was used to provide an objective index of peak-flood potential.

In general, however, the design of structures for flood control demands objective and detailed work which relate rainfall depth, duration and frequency, or which indicate probable maximum precipitation (PMP). About £200 million is spent annually in the United Kingdom on renewing or extending (urban) storm drainage systems which provide for the safe discharge of most rainfall events. Quite small percentage savings arising from the use of design data of improved reliability can lead to national savings of several millions of pounds per annum. As already mentioned (see page 8), the *Flood Studies Report*, to which substantial contributions were made by the Meteorological Office, presents basic depth–duration–frequency relationships for any area in the United Kingdom, together with the likely storm profiles. Knowledge of the time interval before rainfall on a catchment arrives in the storm sewers, and the relation between run-off and rainfall profiles, enables the size of storm sewers to be defined. Each year since publication of the *Flood Studies Report* the Meteorological Office alone has answered about 150 enquiries by engineers at a relatively trivial cost.

Familiarity with the development of the necessary statistics from conventional rainfall observations enabled the Meteorological Office to provide the requisite information for a firm of UK consulting engineers working on feasibility studies for a storm- and foul-sewer system for Damascus, Syria (with a planned population of 1·5 million in the year 2000) and for two other cities. The success of these multimillion-pound projects will be determined in part by information provided by the Meteorological Office at the cost of a mere £1000; it is noteworthy that, in addition to the provision of basic data and their analyses, some appreciation of the general meteorology of the area is important in such studies in order, for

example, to decide whether limited rainfall information can be merged or transposed.

Precipitation rates and duration of rainfall are functions of the availability of atmospheric moisture, the rate at which this moisture can be converted into precipitation and the period over which the attendant atmospheric processes can be sustained. A major difficulty in precipitation studies employing storm models has been to determine how much of the precipitation variation is due to changes in storm mechanisms and how much to orography. However, such models have been used for very recent PMP work by the Meteorological Office for consulting engineers involved on projects in Iran. The method assumes that the most effective combination of rainfall-producing mechanisms has been closely approached in outstanding storms on record. A second assumption is that it is valid to transpose an outstanding storm from the location of its occurrence to a new location; decisions here require a sound understanding of the synoptic meteorology of both locations.

Alternative approaches employing more routine climatological data were used to estimate probable maximum precipitation for three catchments in western Nigeria. After derivation of the data series comprising maximum annual occurrences of daily rainfall, PMP estimates could be obtained from relationships based on the mean and standard deviation of the data, and also from the properties of the fitted distribution curve. Finally, rainfall depth, duration and probability statistics (based on all storm types) were developed and extended to estimate the extreme event.

From time to time scientific staff have been detached to work with engineering groups engaged on projects at home and abroad. This has sometimes entailed on-the-spot study and analysis of local rainfall information and the instruction of local national staff in appropriate procedures. Figure 3 shows those locations for which hydrometeorological work has been undertaken in recent years.

A brochure illustrating many of the services available was issued in 1978.

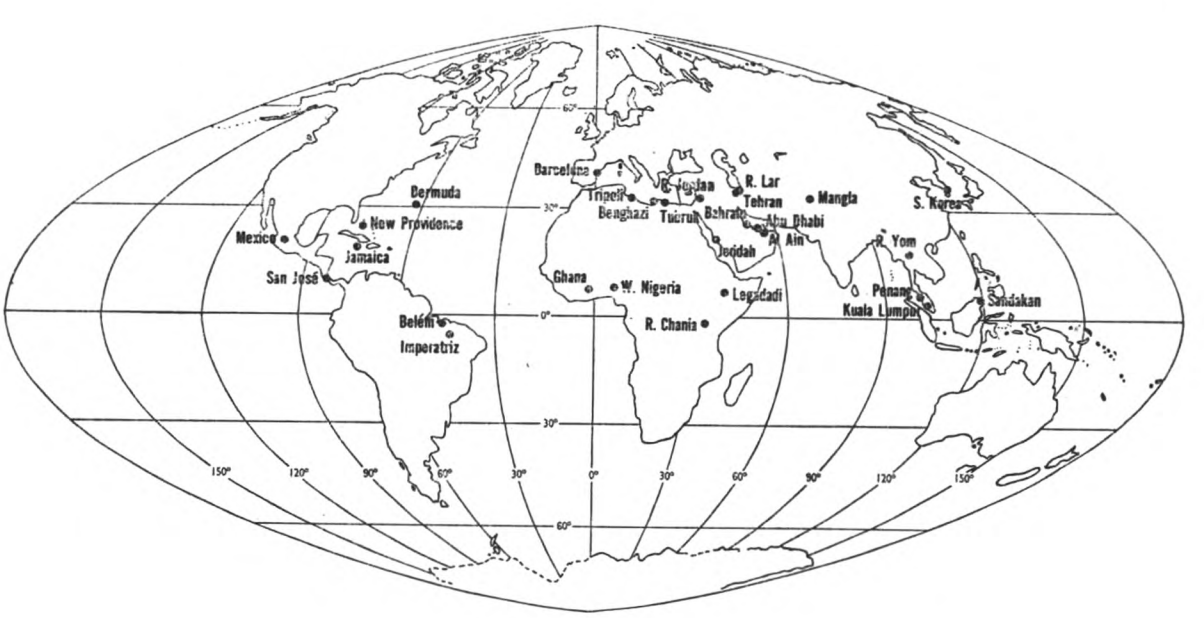


Figure 3—Locations of some hydrometeorological studies carried out by the Meteorological Office

International co-operation

Perhaps it is obvious that international co-operation is necessary for the effective monitoring and reporting of hydrometeorological elements since rain-bearing systems can move rapidly across national boundaries, and rivers may traverse or border sovereign states on their way to the sea. However, to move from this initial concept to effective international collaboration on the details of data collection, transmission, processing, storage, retrieval and publication requires technical expertise and harmonization procedures that can only be developed slowly and often with some difficulty. The desire to benefit from international experience and commonality of practice has led to agreements on the principles of network design and the subsequent standardization of methods of observations and instrumental procedures. Improvements in data application for design purposes and hydrometeorological forecasting are practical objectives that all can recognize, and collaboration covering the interests of operational hydrologists in such matters as water and sediment discharge and water quality has been a further natural outcome.

The Commission for Hydrology of the World Meteorological Organization (WMO) provides a forum for the discussion of these aspects and UK meteorologists and hydrologists have made substantial technical and administrative contributions. This work continues today through the participation of individuals as Rapporteurs or in Working Groups of the Commission. It is now generally agreed that the Commission has additional roles concerned with education and training and in the transfer of technology to the developing countries. Also, it has a duty to encourage the exploitation of the outcome of new technology, such as data provided by satellites, to problems of practical importance in its field and to contribute within its area of competence to broader international programs such as the proposed WMO World Climate Program, it being recognized that rainfall is a key climate factor.

The United Nations Educational, Scientific and Cultural Organization (Unesco) has aims which overlap those of the WMO but, when Unesco launched an International Hydrological Decade (IHD) in 1965, co-operation between the two organizations was quickly achieved, WMO concentrating on operational hydrology and IHD on science and education. The IHD was essentially directed at gathering information about the world's fresh-water resources and the scientific knowledge necessary for their effective management, including that needed for such matters as flood and pollution control. Seminars and training courses to spread such knowledge were important components.

OTHER WORK OF THE DIRECTORATE OF SERVICES

Forecasting Services

Central Forecasting Office

As the chief forecasting centre of the Meteorological Office, the Central Forecasting Office (CFO) fulfils three main requirements:

(a) It provides guidance to outstations of the Office; this guidance is mainly in the form of charts of plotted observations, charts depicting actual and forecast synoptic situations, and advisory texts covering the next three days. They are disseminated by land-line facsimile and teleprinter transmissions.

(b) It is responsible for routine forecasts for sea and land areas and for warnings of hazardous weather conditions such as gales, fog, snow, frost, icy roads, thaw and thunderstorms over the United Kingdom. These forecasts are intended for dissemination by the Press, radio and television, but some are issued direct to public utilities such as the British Gas Corporation and the Central Electricity Generating Board.

(c) At the international level it is a Regional Meteorological Centre in the World Weather Watch plan of the World Meteorological Organization, and serves the needs of a number of National Meteorological Centres in Europe for regional forecasts and guidance covering a large area of the North Atlantic, Europe and the Arctic. This guidance is mostly in the form of charts which are broadcast by radio-facsimile or in coded form by radio-teleprinter.

Analyses and forecasts are produced in CFO by a combination of numerical (computer) methods and subjective (manual) methods. The observational data are processed by a computer, which also provides analysis and forecast guidance for the forecasters. The forecasters monitor these processes, modifying the products in the light of their experience of the behaviour of the weather systems and their knowledge of the characteristics of the numerical analysis and forecast models, and by considering information not used in the numerical system. The latter information may consist of observations that have been received too late to be included in the numerical operational system and data that have been inferred from satellite pictures.

The two forms of the 10-level numerical forecasting model, the coarse-mesh octagon version covering most of the northern hemisphere, and the fine-mesh rectangle version giving more detailed coverage for Europe and the North Atlantic, continued to provide basic guidance to the forecasters. Following the introduction of a long-wave radiation scheme and a revised lower boundary condition into the octagon version at the end of 1977, the representation of topography was further improved in March. Verification statistics for the octagon model showed these changes to be worth while. In April corresponding changes were made in the formulation of the fine-mesh model.

Both versions of the model continued to be run twice a day, based on observations for 00 and 12 GMT. A trial started in 1977, of additional fine-mesh forecasts which provide guidance on rain forecasting using observations made at 06 GMT, was continued for the first part of 1978. Assessments showed that these forecasts were slightly better for a given clock time than those based on earlier 00 GMT data. They provided the Senior Forecaster with guidance in good time for him to give them full consideration before preparing the afternoon forecasts

whereas the forecasts based on 12 GMT observations became available rather too late to be taken fully into account. Thus this additional run of the fine-mesh model based on 06 GMT data was incorporated into the operational routine. Analyses and prognoses of surface pressure, 1000–500 mb thickness and forecast rainfall rates and amounts from the fine-mesh model were sent on a trail basis to the Principal Forecasting Offices (PFOs) at London Airport, and Headquarters Strike Command.

Forecasts for two and three days ahead were issued to meteorological offices throughout the country and internationally. They formed the basis of forecasts for agriculture, industrial and manufacturing interests as well as for the general public and were particularly useful in forecasting for the offshore oil industry. Forecast charts for four and five days ahead were prepared daily by subjective modification of the numerical forecasts by the Medium-range Forecaster. They have been used in CFO for several years for providing extended guidance in a number of fields of activity, mostly for the offshore oil industry and for farming. From October they were issued to other major forecasting centres in the United Kingdom. Guidance was given to outstations for the Dry Spell Service which gives notification to farmers of the onset of conditions suitable for haymaking and harvesting.

A number of services provided by CFO are described in the section on 'Services for Marine Activities'. Sea wave and swell forecasts for periods up to 48 hours ahead for the North Atlantic were required for international broadcast and for use by the Meteorological Office ship-routeing service. The charts of forecast wave height and direction of movement were prepared by the Medium-range Forecaster with guidance from wave forecasting models which use the surface winds predicted by the octagon version of the 10-level atmospheric model. Refinement of the coarse-mesh wave model continued, but the main progress was in the development of a fine-mesh version of the wave-forecasting model based on the atmospheric fine-mesh products. The output of the latter model became an operational tool used by the London Weather Centre. The mesh length of this wave model is 50 km and it allows for the effects of water depth on group velocity, bottom friction and the breaking of waves. A scheme of objective analysis of surface wind observations providing wind data at 3 hourly intervals on the 50 km mesh was introduced. This resulted in improved diagnosis of the initial wave fields. The Branch became further involved in oceanographic forecasting with the incorporation of the storm-surge model, developed by the Institute of Oceanographic Sciences, Bidston, into the operational numerical forecasting scheme in late September. The storm-surge model, like the fine-mesh wave model, is driven by surface wind forecasts from the fine-mesh version of the 10-level model. The results were made available each day to the staff of the Storm Tide Warning Service of the Ministry of Agriculture, Fisheries and Food for evaluation and transmission to Water Authorities responsible for warning of flooding in western coastal districts.

The use of computer terminals in CFO for monitoring and amending data was very successful. Observations identified by the computer as being of doubtful validity are displayed on visual display units (VDUs) to the forecasters who use their judgement to direct the computer system, through the VDUs, to accept or reject the observations or to amend them in some way. Computer analyses and forecasts are monitored and amended in a similar way so that there is a two-way interaction between forecaster and computer. The program

options available on the VDUs were extended during the year. A Gale Warning Construction Program was developed which will reduce the time spent by the Deputy Forecasters in writing gale warning messages.

The objective analysis programs were modified in a number of ways. Better use was made of observations of strong winds in the upper air and wind data inferred from the Japanese geostationary satellite over the eastern Pacific Ocean were introduced in the analyses. A number of tests were conducted, in collaboration with the High Atmosphere Branch, to assess the values of winds inferred from METEOSAT, the European geostationary satellite. Objective analyses of humidity were improved by using surface observations in estimating humidity in the upper air.

A major task of the computer support section was the maintenance of the operational suite of programs which was modified to deal with changes in international codes, in station numbers and in the COSMOS system. The section tackled a large variety of operationally oriented tasks in addition to those already mentioned. These included the tailoring of numerical forecast products of wind speeds in jet streams by the numerical weather forecasting system. Changes in the time of issue of briefing documentation by the aviation forecasters for civil aviation flights from Western Europe to the North American continent were made so that 18 hour and 24 hour forecasts can be used instead of 24 and 30 hour forecasts. This enables aircraft fuel requirements to be assessed more accurately. Special forecasts were made for Concorde flights to Washington, New York and Bahrain, including those flights made from Paris. CFO also provided meteorological advice, including forecast air trajectories, for the successful American crossing of the Atlantic by balloon. A similar service was given for the earlier British attempt which so nearly succeeded.

Cloud pictures from weather satellites continued to make a valuable contribution to the preparation of surface analyses over the North Atlantic and European areas. Nephanalyses continued to be prepared in CFO and these were almost entirely based on the NOAA-5 satellite cloud pictures.

The data tabulations for the *Daily Weather Report*, the *Monthly Summary* and the *Daily Aerological Record* were produced by two Datamatic typewriters controlled by papertape. Programs for automating the plotting of the published charts were developed. However, manual plotting continued pending the discovery of a medium suitable for replacing the wax stencils for both the tabulations and the charts.

Services for industry, commerce and the general public

The Office performs its function of providing meteorological services to industry, commerce and the general public in two distinct ways. In continuation of a long tradition, general weather forecasts are made widely available at little or no cost to the recipient. Information of this kind is disseminated by means of the Press, radio, television, the Automatic Telephone Weather Service (ATWS) and through teletext facilities provided by the BBC and the Independent Broadcasting Authority (IBA). Certain meteorological offices also answer simple telephone enquiries calling for information that is readily to hand. However, many human activities are highly weather sensitive and increasingly, for both safety and economic reasons, detailed forecasts of special kinds are needed. These are provided on a commercial basis. The Meteorological Office

is expected to make its contribution to planned reductions in Defence expenditure so that, to meet increasing demands for services and to improve the already high standard of professional output, it is necessary to expand revenue-earning business. Therefore, without neglecting the traditional free services, particular efforts have been devoted during 1978 to commercial services.

Whereas the Press coverage of routine weather information varies little over the years, it seems characteristic of both radio and television that scheduling and program changes are introduced much more frequently and 1978 has provided no exception to this pattern. On BBC Radio 4 the short live broadcasts at 0735 and 0835 were dropped in favour of a summary forecast script read by an announcer at 0730 and 0830. To enable brief information about Scotland, Wales and Northern Ireland to be given as well as the detailed forecast for England, the main live broadcasts from London Weather Centre were extended to 2½ minutes when necessary. A further 30 seconds were made available on Friday mornings to allow the forecaster to give brief general forecasts for Europe concentrating on the main holiday areas. The late-night weather report and forecast proved popular and the outlooks given in this live broadcast were extended to five days whenever the weather situation permitted. As a result of the reorganization in November of frequences used by BBC Radio, there were significant repercussions on the pattern of broadcasts from Radio Scotland and Radio Wales. Shipping forecasts and gale warnings were transferred from Radio 2 to Radio 4 but other changes of weather broadcasts were of a minor nature.

In addition to the specialist weather information transmitted for the benefit of mariners, yachtsmen and inshore fishermen, live weather broadcasts were included in radio and television programs aimed at the farming community. The presentation by the BBC Television weatherman at the end of the 'Farming' program on Sunday afternoons dealt with matters of topical interest to farmers and outlined the weather patterns to be expected through the week ahead. These broadcasts have always been popular and interest has been expressed in having a similar type of broadcast in mid week. London Weather Centre forecasters have, for many years, contributed a 1 minute spot in the early morning 'Farming Today' program on Radio 4. This was extended to 2 minutes on Thursday mornings to permit inclusion of the expected weather trends for the next seven days. As a contribution to publicity for weather forecasts for farmers, the BBC produced a video-cassette describing the special weather presentation in 'Farming'; this was used at a Meteorological Office stand at the Royal Agricultural Show.

Two changes were made to the broadcasts on BBC Television during the year. A live presentation was introduced following the main news on Friday evenings to cover the weather outlook for the weekend and it is hoped that a live broadcast at this time will eventually become a daily feature. The introduction of high quality satellite pictures as a regular part of the weatherman presentations was discussed at length with the BBC and prospects for this are good. As an interim measure pictures from the European Geostationary Satellite METEOSAT were shown in the late night presentations on Thursday evenings.

Scripted forecast services were provided to many of the independent television companies and commercial radio stations and information was also made available to those commercial television companies which employ professional weathermen. Scripts were regularly supplied to BBC local radio stations and

routine live broadcasts were made by Meteorological Office forecasters in several parts of the country. Over and above the routine weather broadcasts Office staff contributed many prepared contributions and interviews during the year on both radio and television. These were mostly on matters of topical interest and a selection is included in Appendix II (page 143). Worthy of special note was the well-received program 'We had rain—We had sun' shown on BBC Television on New Years Day; this gave a review of the weather in 1977 and all four weathermen took part. On radio the most notable non-routine program was a documentary 'The Fifty Year Forecast' which discussed various aspects of weather forecasting and climatic change and featured several contributions from the Director-General.

Considerable use continued to be made of the Automatic Telephone Weather Service, the total number of calls being 24 467 679 in 1978 compared with 19 040 617 in 1977. Although forecasts for many parts of the country are now available through this Service, there are still very large gaps in the more sparsely populated regions and efforts to achieve a wider coverage continued.

Teletext, the system in which a television screen is used to display broadcast information, was introduced some years ago by the BBC Ceefax and by the IBA Oracle. Weather information was supplied for these services. Notwithstanding limitations on the amount of information that can be carried by teletext, both systems asked for and were supplied with a greater amount of weather data in 1978 than in 1977.

The entry of the Post Office into the related field of Viewdata is a major development in which the Meteorological Office has participated fully. Whereas Ceefax and Oracle convey information by using spare lines in the television signal, the Post Office system, Prestel, enables the user to interrogate a data bank by using a keypad connected to an ordinary telephone line. The information is displayed on a suitably modified domestic television set and the range and quantity of information available is potentially vast, being limited only by the capacity of the controlling computer and the ability of Information Providers to supply data for the bank. The user of the system, apart from paying the Post Office the cost of a telephone call, pays a surcharge for each frame of information requested. This surcharge is fixed by the Information Provider, to whom it is passed by the Post Office less a small handling charge. Unlike Ceefax, Oracle and ATWS therefore, this system offers the prospect of substantial revenue for the Office in future years when it is fully established. Another interesting feature is that access to particular sets of data can be restricted to members of a closed user group specified by the Information Providers; this offers new possibilities for the fast distribution of specialized, commercially valuable meteorological information.

The test service of Prestel began during the summer. From that time information was entered into the Post Office data bank using a remote-entry terminal located in the Central Forecasting Office at Bracknell. A market trial started in September and in addition to national forecasts and caption charts the information presented included local and specialized forecasts and also actual weather reports and climatological information from the United Kingdom and other countries. Although most of the climatological information will stand for a long time, the forecasts and weather reports are highly perishable and need regular and frequent updating. For this reason the input terminal has been manned throughout the 24 hours.

The Weather Centres at London, Glasgow, Manchester, Southampton, Newcastle and Nottingham were established solely to provide free and commercial services to industry, commerce and the general public. In parts of the country where it has not yet been possible to set up a Weather Centre, meteorological offices at certain civil airfields and Royal Air Force stations have been designated to provide these services. The services available at all these offices are detailed in a free brochure, 'Weather Advice to the Community', which is available from any meteorological office. The total number of enquiries to all offices continued to increase, and the figures for the Weather Centres over the past three years were as follows:

	London	Glasgow	Manchester	Southampton	Newcastle	Nottingham
1976	299 160	107 388	117 096	100 342	99 824	62 423
1977	307 539	109 640	132 659	109 700	99 144	65 019
1978	306 993	123 077	164 290	106 220	109 988	71 306

Grand totals: 1976, 786 233; 1977, 823 701; 1978, 881 874.

To meet the common needs of a number of clients, specialized services have been developed. For example, there is a service designed to meet the highly specialized requirements of the offshore oil and gas industry. This is available from the London Weather Centre or from the public service office at Aberdeen Airport and is described more fully below under 'Services for Marine Activities'. Specialized services are also available for issue of Road Danger Warnings to highway authorities, dry-spell forecasts for farmers, weekend temperature forecasts to help with fuel economy at industrial or other premises, forecasts for pigeon races and so on. All Weather Centres provide summaries of the weather in their area. In no sense is a potential customer asked to accept an 'off-the-peg' service if it does not meet his requirements. Services tailored to suit individual needs are developed as necessary and these make up the majority of the total services provided. In the latter category come the forecast services developed for the gas and electricity industries to assist them with the difficult task of demand prediction; these forecasts make an important contribution to the economics of the power industries and thus help to reduce the cost to the consumer of gas and electricity. Many other examples could be given of services developed to meet specialist requirements as diverse as those for sweet manufacture, railway operation, coal mining, horticulture, food distribution, river management and the operation of greyhound racing tracks.

Although telephone and telex were still the most commonly used means of distributing forecast information, increasing use was made of document facsimile which can handle tabulations, charts and even satellite pictures. The equipment was used both to communicate with clients and to send to meteorological offices information of a specialist nature which was commercially confidential and so inappropriate for transmission on facsimile broadcasts. The signals are sent over an ordinary telephone line, so that with co-operation from the Post Office the system was used most successfully to provide up-to-date information to forecasters on location for special contracts (for example at the offshore platform construction yard at Loch Kishorn), and at exhibition stands.

During 1978, Meteorological Office stands at two important exhibitions for the offshore industry were sponsored by the Ministry of Defence Directorate of

Promotions and Facilities and were professionally designed and produced by the Central Office of Information. These stands demonstrated forecasting and climatological services, marine instrumentation and ship routeing and included a working automatic weather station which could be used on a buoy or platform. Telephone, teleprinter and facsimile communications made it possible to provide a small forecast office which dealt with current weather. An important innovation at Oceanology International 78 held at Brighton in March was a remote terminal by means of which basic and processed information could be obtained on line from a marine data bank in the COSMOS computer at Bracknell. The stand at Brighton and that at the European Offshore Petroleum Exhibition at Earls Court in October were manned continuously by Meteorological Office staff. Both attracted a great deal of attention and many useful contacts leading to new business were made. Publicity is an important part of the drive to expand commercial services. A modest amount of Press advertisement, primarily directed at the offshore industry was undertaken because the Office is in competition with commercial consultants working in this field.

To permit advantage to be taken of any opportunity to publicize services a set of display boards has been designed and prepared jointly by the Public Services Branch and by the Cartographic Section of the Office. These were used on many occasions during 1978 including a 'Climate and Weather Exhibition' in the Isle of Wight, an 'Open Day' at RAF Upavon, a 'Physics at Work Exhibition' organized by the Institute of Physics at the University of Surrey and the special exhibition arranged by the Royal Meteorological Society to mark the occasion of the visit to Bracknell by Her Majesty The Queen. The brochures 'Sail Weather Wise', 'Offshore Weather Services' and 'Meteorological Services for Shipping' were revised and new brochures entitled 'Hydrometeorological Services' and 'Meteorological Services for Agriculture' were issued.

Three other aspects of public relations deserve mention. An increasing number of applications to visit Headquarters Bracknell is received from schools, colleges and societies. During 1978 parties came from as far afield as Sheffield and Wrexham and the numbers were such that bookings normally had to be made at least nine months in advance. Similar visits were also made to Weather Centres and other public service offices, whose staff shared with those at Headquarters the onerous task of replying to the vast amount of correspondence that is received from the general public. This ranged from the quest for simple information from primary school children to advanced technical queries from professional bodies and individuals. Being in the public ear and eye by virtue of radio and television broadcasts, staff at Weather Centres and public service offices received many requests for talks to schools, colleges, societies and professional institutions. A high proportion of these were given on a voluntary basis in the speakers own time, and a selection is given in Appendix II (page 143).

Services for the general public (overseas)

Meteorological offices serving the Royal Air Force stations in Malta and Gibraltar continued to provide forecasts for the general public by means of Press, radio and television and to cater for the needs of local government departments, oil-drilling operators and engineering and commercial concerns

in accordance with the charging policies which are applied to the provision of similar services in the United Kingdom.

Services for marine activities

As the offshore oil and gas industry in the North Sea moved from the exploration to the production phase, the demand for forecasting services in support of rigs and platforms inevitably declined. However, exploratory drilling was extended into areas west of Shetland and south-west of Cornwall, and the highly weather-sensitive activities connected with platform construction and installation, and with the operation of tanker terminals, introduced new requirements. During 1978 some aspects of the Meteorological Office organization were adjusted to meet these changing demands and overall involvement on a commercial basis continued at a high level.

At the core of the commercial organization was the London Weather Centre team of experienced forecasters who specialize in offshore wind, wave/swell and weather forecasting and who maintain close daily contact with the operators. By means of facsimile links, the team was provided with considerably more advisory information than was possible a year or so ago, including both the latest pictures from polar-orbiting satellites and from METEOSAT, and a great deal of output from the COSMOS computer complex at Bracknell, some of which is unique material resulting from the running of special programs written to produce detailed wind and wave/swell forecasts. Close support and advice is provided by the Central Forecasting Office (CFO) at Bracknell. From this solid base there was little difficulty in extending the area of operations from the North Sea to other parts of the continental shelf.

Good communications are an essential part of any efficient commercial information service, and in addition to using telex and radio telephone, London Weather Centre can now communicate its products to customers by means of document facsimile. This development has also assisted with the establishment of subsidiary forecasting offices in Scotland to serve offshore industrial interests. The meteorological consultant based at the Offshore Supplies Office in Aberdeen was moved to the forecasting office at Aberdeen Airport and two forecasters were added to his staff. Under the technical control of London Weather Centre, a local forecasting service for offshore industrial activities in the east of Scotland and face-to-face briefing for those operators based in Aberdeen who require this facility was provided. The role of the meteorological office at Kirkwall Airport was broadened to provide a meteorological service for the tanker terminal at Flotta in Orkney, and a completely new forecasting unit was established at Lerwick Observatory primarily to serve the tanker terminal at Sullom Voe in Shetland. For marine matters, both these offices are, like Aberdeen, advised and fully supported by London Weather Centre.

Two forecasters from the London Weather Centre were deployed to Loch Kishorn, the construction site of the Ninian oilfields central platform. The construction engineers made full use of this facility, which in particular helped them to select, 5 days ahead, a weather window for the extremely sensitive operation of mating the deck with the platform. After a short postponement, due to a correct forecast of poor weather, the structure (which was the largest man-made object ever moved at sea) left Loch Kishorn in early May and was successfully positioned at the Ninian oilfield. A forecaster from the London

Weather Centre remained on board the lead tug to give meteorological advice through the tow.

As part of a continuing effort to improve the accuracy of offshore forecasts, the Principal Meteorological Officer at London Weather Centre has instituted a program of forecast verification from which useful lessons were learnt. In response to requests from certain offshore operators, he also conducted trials of possible new methods of forecast presentation in terms of confidence limits applied to the exceedance or otherwise of operationally significant thresholds. It is hoped that these experiments will lead to optimization by offshore operators of the use of weather windows and to the minimizing of the time they are unable to operate owing to adverse weather conditions. The Principal Meteorological Officer maintained close liaison with the industry and its needs by serving on the Oceanographic Committee of the United Kingdom Offshore Operators Association and on a sub-committee of the International Exploration and Production Forum. He is also a member of the North Sea Meteorological Panel which was set up by the Directors of West European Meteorological Services to co-ordinate meteorological activities in support of offshore industrial operations over the continental shelf.

As a result of a survey on marine meteorological services to shipping conducted in 1976 throughout the shipping and fishing industries, the 'North Atlantic Weather Bulletin' for shipping was extended in January to include a new sea forecast area named Trafalgar, to the south of area Finisterre. For most of 1978, services to shipping via BBC Radio and Post Office Coastal Radio stations continued as in previous years but in November, when the BBC introduced frequency changes, the Coastal Shipping Bulletin was moved from BBC Radio 2 to Radio 4. An advantage that arose from this change was that the program pattern on Radio 4 permits the Shipping Bulletins to be broadcast at the same time every day of the week. The opportunity was also taken to include a forecast for the new sea area Trafalgar in one of these broadcasts daily. The Inshore Waters forecasts remained at the same times as before on BBC Radios 3 and 4. A growing number of BBC local radio stations also now transmit forecasts designed for local inshore yachtsmen and fishermen.

The Weather Centre at Southampton has developed specialized services for yachtsmen. In support of forecasts, charts can now be sent by document facsimile to yachting marinas, regular broadcasts are made on BBC Radio Solent and many enquiries are answered. A consultative service backed by facsimile charts was provided for Cowes Week; similar assistance was given to the Royal Thames Yacht Club for the Half Ton World Championship and special briefing arrangements were made for the British team. A Meteorological Office stand at the Southampton Boat Show attracted a great deal of interest from hundreds of visitors and staff manning it were kept in almost continuous discussion. The Meteorological Office 'Plotting Chart for Yachtsmen' still sells in large numbers at the Weather Centre.

CFO supplied guidance forecasts and warnings to forecasters on board the Trawler Support Ship stationed in the waters around the coasts of northern Norway between North Cape and Bear Island during the winter months from late November until the end of April. The forecaster on the support ship maintained close liaison with the British fishing fleets in the area, issuing local forecasts and warnings of gales, storms and ice accretion. During the period when there was no forecaster abroad the support ship, forecasts and warnings were sent

directly to the fishing fleet from CFO. When time permitted, the forecaster also made bathythermograph (deep sea temperature) soundings on behalf of the Navy Department.

CFO works closely with the officers of the Storm Tide Warning Service who are responsible for issuing alerts on occasions when unusually high tides caused by strong winds give rise to the risk of flooding on the east coast of England. Oil slicks and pollution at sea are other emergencies in which CFO played a part by providing forecasts and meteorological advice.

CFO, in common with the London and Southampton Weather Centres, dealt with numerous requests from ships at sea, mariners and yachtsmen. The meteorological office at Pitreavie also continued to provide a winter forecast service for the benefit of North Sea fishing vessels. The office issues forecasts covering a 72 hour period daily from October to March. Forecasts for ships of the Royal Navy were supplied by the Pitreavie and Plymouth meteorological offices whilst the Aberporth meteorological office provided support for Royal Navy ships undertaking trials in Cardigan Bay. Royal Air Force marine craft at home and abroad were provided with forecasts by the nearest meteorological office.

For much of the year, daily forecasts of wind, weather and sea conditions at Sines in Portugal were provided by the Gibraltar meteorological office in connection with dredging operations at the port.

A ship-routeing service is provided to advise on North Atlantic and North Pacific passages and to offer advice in regard to the movement of tows. Advice is also given to vessels on passage in other parts of the world on request. For conventional vessels the object of the service is to select the best route for a ship to follow in order to reach its destination in the shortest possible time with the most economical fuel consumption commensurate with the least damage to the ship and cargo. Data are extracted from a vessel's deck log-book in order to determine the vessel's response to various sea wave fields and a ship/wave performance curve is constructed. However, the service has now amassed a considerable amount of ship performance information for various types of vessels and it is frequently possible to construct a wave/speed curve from basic ship size and type data without recourse to the deck log-book. The forecasters of CFO supply the ship-routeing officers, who are all Master Mariners, with wind and sea predictions up to 72 hours ahead at 12 hourly intervals and this information is used in conjunction with the performance curve to determine the most favourable course for the vessel to follow. Subjective consideration is also given to the loading state of the vessel, to sea surface currents, navigational hazards such as shoals, ice and areas of fog. Later stages of the voyage are also borne in mind. Communication with the vessel to be routed is usually by telex prior to sailing and via pre-determined coastal radio stations whilst on passage. Routeing advice to tows which do not have too restrictive weather parameters is similar to that provided for conventional ships but allowance is made for the slower speed of the tow and for their reduced manoeuvreability. For tows with limiting weather factors—which may be wave height or period, amount of heel or wind force—the routeing service advises when and where to seek shelter or when to resume passage.

There was also a large increase in the provision of marine climatological data, particularly to the offshore industry, and this is discussed more fully in the section on climatological services (page 32).

Services for civil aviation

The Meteorological Office gives professional advice to the Civil Aviation Authority (CAA) on all meteorological matters and in accordance with CAA requirements makes available the staff and technical facilities needed to provide meteorological services for civil aviation in the United Kingdom.

Reliable observations of weather at airfields are of paramount importance and observing offices are maintained at airports throughout the United Kingdom. Routine reports are prepared hourly or half hourly and a continuous watch on the weather ensures that intermediate reports are also made whenever changes of internationally agreed operational significance occur. These reports are rapidly exchanged between airports in Europe and the Mediterranean area by means of the Meteorological Operational Teleprinter Network in Europe (MOTNE).

Forecasts of upper winds and temperatures at ten levels up to 100 mb (53 000 ft $\approx$ 16 000 m) are provided by numerical methods using the COSMOS computer at Bracknell. This output is examined by a team of specialist upper-air forecasters in the Central Forecasting Office (CFO) and appropriatc adjustments are made to cover the needs of aviation; for example, to define more precisely the structure of the jet streams. Data in grid-point format derived from these forecasts are sent over a special line to British Airways for direct input to their flight-planning computer and similar arrangements for other airlines are under discussion. Information in this form was also supplied directly to Prestwick for air traffic control purposes.

A Principal Forecasting Office (PFO) at London/Heathrow Airport provides guidance concerning en-route conditions for flights from the United Kingdom to destinations in Europe, the Mediterranean area, Canada, and the USA. Upper-air forecasts produced by the specialist team at Bracknell are passed to the PFO at Heathrow where charts of significant weather are prepared. All this information is then made available at airfields throughout the country by means of a civil aviation meteorological facsimile (CAMFAX) broadcast. As the PFO at Heathrow is designated by the International Civil Aviation Organization (ICAO) as the Area Forecast Centre for flights from any departure airfield in Europe to Canada and the USA, the information is also sent by land-line facsimile to Dublin, Paris, Frankfurt, Rome, De Bilt and Copenhagen and by radio-facsimile to more distant recipients. Another responsibility of the PFO at Heathrow is that of issuing warnings of weather hazards significant for aircraft flying in the London and Shanwick (Oceanic) Flight Information Regions which together cover most of England and Wales and a large area of the Atlantic west of Ireland; similar services covering Scotland and Northern Ireland are provided by the Main Meteorological Office (MMO) at Prestwick.

Forecasts of weather conditions at airfields are prepared for planning purposes by aviation forecasters located at meteorological offices throughout the country. These are exchanged world-wide for use by aircraft captains and flight planning staff. To assist air traffic controllers and pilots, special short period (TREND) forecasts of landing conditions are appended by local forecasters to the routine weather reports for their own airfields; these are disseminated both on MOTNE and by VHF radio broadcasts to aircraft in flight. Pre-flight documentation is prepared at departure airfields using the en-route and landing forecast information distributed on CAMFAX and MOTNE broadcasts. Pre-flight briefing is

also provided when required by local forecasters at departure airfields. Building developments needed to deal with the growing number of aircraft movements have at many airports increased the distance between forecast offices and terminal blocks; face-to-face briefing is no longer always possible but telephone links to meteorological offices are available and experiments with the use of closed-circuit television as a briefing aid are planned for Edinburgh/Turnhouse Airport.

Whereas the need for personal briefing of pilots operating scheduled services for the major civil airlines is less than was the case some years ago, the meteorological requirements of the smaller airlines and of general aviation (executive aircraft, air taxi services, private flying, etc.), both of which may operate below controlled airspace, are more exacting. Specialized services for these aircraft are provided on request by local forecasters at civil and RAF meteorological offices and these call for detailed assessment of cloud, visibility, low-level winds and weather hazardous for light aircraft and for those which carry few navigational and landing aids. Personal briefing is often still necessary for pilots of these aircraft. To help those operating from small airfields where there is no meteorological office, the PFO at Heathrow and the MMO at Manchester Airport prepare forecasts of flight conditions in each of a number of defined areas covering England and Wales. These forecasts are recorded and may be heard by dialling specified public telephone numbers. Information given includes a brief description of the synoptic situation, relevant warnings, upper winds, freezing level and a code letter indicating the range of cloud and visibility conditions in each area from which pilots can assess whether flights under visual flight rules are appropriate. This is known as the General Aviation Visual Flight Forecast service.

There has been a continued expansion throughout 1978 in aviation activity in support of the offshore oil and gas industry and, in terms of aircraft movements, the airfield at Sumburgh in Shetland is now one of the busiest in the country. Flights by helicopter to rigs and platforms in the North Sea require a specialized meteorological service in which particular attention is paid to low-level conditions including visibility, cloud base, icing, and the direction, speed and gustiness of the wind. Forecasts for flights to installations in the southern North Sea are prepared by the meteorological office at RAF Honington. Services for helicopter flights over all northern waters are provided by MMO Prestwick. To meet the rapidly growing demand, the area of responsibility has been divided into a number of sub-areas for which forecasts are now issued every six hours. In many cases these forecasts are sent directly to the aircraft operators as well as to the subsidiary meteorological offices at the main airfields from which the helicopters operate. A new forecasting office at Sumburgh was opened in March and the two forecasters there have been kept extremely busy providing meteorological services for the fixed-wing aircraft and helicopters now using Sumburgh and other smaller airfields in Shetland. A share of the increased work was absorbed by the forecasting office at Kirkwall in Orkney. Aberdeen/Dyce Airport was also extremely busy.

To maintain safe vertical separation during flight the same pressure value must be set on the sub-scales of the altimeters of all aircraft in a given area. For flights at low levels it is necessary to take account of the surface pressure and this varies considerably both in space and time. Altimeter Setting Regions (ASR) are therefore defined and every hour forecast minimum pressure values

for each ASR are prepared at CFO Bracknell; these figures are distributed rapidly on teleprinter circuits to all parts of the country so that pilots can be advised of the appropriate settings. The increase in numbers of helicopter flights over northern waters necessitated an extension of the area covered by altimeter setting procedures to cover this region and new arrangements came into force during November. Earlier in the year a new Cotswold ASR was introduced to reduce the number of settings needed by low-level aircraft operating in the upper Thames Valley area.

The MMO at Preston was closed at the beginning of March and at the same time the office at Manchester Airport was upgraded to MMO status, taking over the aviation commitments previously met by Preston. The change went very smoothly and the staff involved in the move showed great initiative to ensure that there was no interruption of services.

Plans were made to move the PFO at Heathrow from its present location in the Queen's Building to lighter and more compact accommodation within the Air Traffic Control Tower building. The move is expected to take place in 1981 and provides a welcome opportunity to re-design and streamline the operation of the PFO. The planned introduction of computer-controlled chart-plotting equipment and the installation of quiet teleprinters in the forecast room will make for greater efficiency and lead to economies of staff.

Looking to the future, the provision of meteorological services for civil aviation in the light of modern aviation practice is under examination by the Meteorological Services Review Committee which comprises representatives of the Airline Operators, the Civil Aviation Authority and the Meteorological Office. So far, discussion has concentrated on the needs of the major civil airlines. The requirements of general aviation remain to be considered.

Civil aviation is very much an international matter, and it is essential to reach agreement on standards and procedures. This is the business of ICAO. Each Region of the world is responsible for its own air navigation plan and these inevitably require continuous development. The European Air Navigation Planning Group has established a Meteorological Advisory Group (METAG) which met in February and September. A member of the Meteorological Office attended both meetings as part of the United Kingdom delegation. An advisory group for telecommunication problems associated with MOTNE was also set up and the Meteorological Office provided a representative for the United Kingdom delegation to the meeting of this group held in May.

Services for civil aviation (overseas)

Services for civil and general aviation were provided from the offices at Royal Air Force stations in Malta and Gibraltar in the Mediterranean and at Wildenrath and Gütersloh in Germany. The United Kingdom forecasters at Luqa airport in Malta were withdrawn in October as part of the plan leading up to the final withdrawal of the United Kingdom military presence from Malta in March 1979. The office at Luqa was reduced from a Main Meteorological Office to a civil airport office manned by Maltese forecasters and assistants trained by the Meteorological Office in accordance with the 1972 Agreement with respect to the Use of Military Facilities in Malta. A United Kingdom Principal Meteorological Officer remains in overall charge until final withdrawal.

Services for military aviation

Senior officers of the Meteorological Office are located at Headquarters Strike Command and at Headquarters Royal Air Force Germany. These officers act as advisers on meteorological matters to their Air Officers Commanding-in-Chief and they are responsible for the organization of meteorological services to meet the needs of Strike Command and the Royal Air Force in Germany.

The forecasting services for the Royal Air Force and the Army Air Corps at home continue to be provided by offices which are grouped largely in conformity with the RAF organization. A Principal Forecasting Office (PFO) at Headquarters Strike Command and Main Meteorological Offices (MMOs) at various centres, functioning 24 hours a day, control and advise subsidiary forecasting offices located on airfields, enabling them to meet the requirements of military aircraft operating in widely differing roles. At subsidiary forecasting offices a forecaster is on duty at times which depend on the stated requirements of the Royal Air Force and the Army Air Corps. Many of these offices also provide services for civil aviation and for the general public.

The PFO at Headquarters Strike Command and the MMO at Headquarters 38 Group prepare a comprehensive six-hourly program of area and route forecasts in chart form which is issued by facsimile to subsidiary forecasting offices to meet most operational requirements. The routine issues include forecast charts of the surface-pressure distribution and significant weather in addition to forecasts of winds and temperatures for standard upper levels.

The powerful computer system at Bracknell provides major support to the offices serving military aviation. During the year computer-produced forecast charts of upper winds and temperatures were introduced in a format suitable for direct use in flight forecast documentation. The charts were well received by aircrew. However, the personal briefing of aircrew and operational staff is considered by the Royal Air Force and the Army Air Corps to be an essential service for the foreseeable future.

Mobile meteorological units support certain Royal Air Force and Army elements in the field and they participated in exercises in the United Kingdom and overseas. Each unit has its own air-transportable sets of instrumental and communication equipment for use at locations away from permanent meteorological offices. The sets include radio-teleprinters, radio-facsimile recorders and equipment for receiving weather satellite information. Forecasters in the mobile units hold commissions in Class CC of the Royal Air Force Reserve of Officers.

Offices were opened temporarily for short periods at certain locations to provide services during large-scale exercises and special operations. A forecaster was again detached to Barksdale, Louisiana, to provide support to the RAF team participating in the United States Air Force Bombing and Navigation Competition.

The provision of services for the Royal Air Force in Germany continued unchanged. A Main Meteorological Office at the Joint RAF/Army Headquarters at Rheindahlen supported subsidiary forecasting offices at the four airfields of RAF Germany and at the Army Air Corps airfield at Detmold.

United Kingdom defence requirements in the Mediterranean were met by Main Meteorological Offices in Cyprus, Gibraltar and, until October, Malta. Residual defence needs at Malta after October were met by the civil meteoro-

logical office. Following the destruction of the Main Meteorological Office in Cyprus in an aircraft accident in December 1977 the office operated under difficult conditions in temporary accommodation until it was rehoused in permanent accommodation near its original location in July.

Radiosonde units are located at Gibraltar and Malta and limited upper-air observations are carried out in Cyprus using Grawsonde equipment. The radiosonde unit at Qrendi in Malta was withdrawn at the end of the year and plans were made to substitute Grawsonde observations for the obsolete Mk 2B radiosonde system in Gibraltar.

The voice-broadcast from West Drayton of plain-language reports from major RAF aerodromes (VOLMET) was continued. This broadcast is provided mainly to meet the needs of RAF transport aircraft returning from overseas to bases in the United Kingdom. Consideration is being given to the possible automation of the supply of data for this broadcast.

The Office continued to meet the requirements of the Royal Air Force for meteorological training by the provision of lectures and tutorial assistance.

Other services for the Army and Establishments of the Procurement Executive, Ministry of Defence

Offices are maintained at the Royal School of Artillery, Larkhill, at the Royal Aircraft Establishment (RAE), Aberporth, and at the Proof and Experimental Establishments (PEE) at Shoeburyness, Eskmeals and Pendine. The office at Larkhill also provides meteorological support for RAE and PEE units located within the Salisbury Plain area. The office at Shoeburyness supports the Atomic Weapons Research Establishment at Foulness. The replacement of the radiosonde equipment by the Mk 3 system is taking place at Aberporth, Shoeburyness, Eskmeals and Larkhill.

Meteorological Office staff were attached to the Army practice camps at Sennybridge and Otterburn for several periods during the year to provide meteorological information for ballistic purposes and to the Hebrides Rocket Range for a program of missile firing during May and July.

Information was provided for a number of projects connected with the development of weapons and military equipment.

Liaison with the Navy Department

Close co-operation is maintained with the Director of Naval Oceanography and Meteorology to ensure the co-ordination of plans to meet the requirements of all three Services at home and overseas.

International defence services

The Meteorological Office continues to participate actively, on behalf of the United Kingdom, in the work of NATO and CENTO committees concerned with the international co-ordination of meteorological support for military needs, and contributes to studies associated with that support. The chairmanship of the Meteorological Group of the NATO Military Committee remained with the United Kingdom during the year. The Office continued to play its part in various NATO exercises.

Services for the Home Office

The meteorological requirements of the UK Warning and Monitoring Organization (UKWMO) of the Home Office were kept under review. Detailed plans for meeting, as effectively as possible, the requirements of UKWMO continue to be developed and practised in regular national and international exercises in which Meteorological Office staff take part. Lectures have been given to groups of Home Office Sector Scientists, Chief Warning Officers, and members of the Royal Observer Corps who are equipped and trained to make observations at ROC posts in times of emergency.

Services for nuclear establishments

Arrangements for Main Meteorological Offices to supply information to nuclear establishments of the United Kingdom Atomic Energy Authority and the Electricity Generating Boards in the event of accidental release of radioactive or toxic material were extensively reviewed and exercised. Similar arrangements cover emergencies which may arise from nuclear submarines in port or from radioactive material in transit over land.

Climatological Services

As considerable effort goes into the collecting, quality control and archiving of meteorological observations, it is pleasing that the number of enquiries utilizing this information is now at a record level. This year climatological enquiries exceeded 30 000 for the first time. Perhaps the most dramatic increase has been in marine climatology, with considerable interest from the offshore industry, and revenue here has been about £25 000, compared with £1300 in 1975, £3300 in 1976 and £5700 in 1977.

Data acquisition

The basis for all climatological work is meteorological observations, and the Office is very much indebted to the large number of private individuals and various public bodies who run stations in the climatological network (see Table IV on page 70). The number of stations in the network has remained fairly constant in recent years, but with inevitable closures there is an ever present need to find new stations. This turnover of stations emphasizes the importance of observations from the all too few long-period stations.

In future years it is hoped that some of the gaps in the network, especially those in the less populated areas, will be filled by automatic observing systems. In particular, work is well advanced for the bringing into service of the Digital Anemograph Logging Equipment (DALE) and it is expected that at least 20 of these will be introduced next year. As the name implies this equipment will be used for recording wind information, but other developments are planned to cover additional meteorological parameters.

Each month tabulated observations are sent to Bracknell, Edinburgh and Belfast. A revised form for this purpose to ease problems experienced at some

voluntary co-operating stations, was introduced from July and has had a favourable reaction from observers. The information this provided is used to answer some enquiries directly, but the keying of the data for the computer is an essential step in many applications, allowing large amounts of data to be assembled and analysed easily. This process enables a consistent and thorough quality control to be carried out by computer methods whereas the corresponding human scrutiny of so much information would be impracticable. Queries generated by the quality-control tests are resolved individually with reference back to the observer as necessary. Early in the year particular difficulties were encountered with the data gathered during periods of extensive and heavy snowfalls.

The archive is maintained both in manuscript and in computer data-bank form. The computer archive is not so extensive, but it expands year by year as new data are added and attempts are made to extend the archive backwards by including earlier data, though the size of this task is formidable.

Land climatology

Climatological enquiries are handled at Bracknell (for England and Wales), at Edinburgh (for Scotland) and at Belfast (for Northern Ireland). The total number of enquiries continued to rise (see Table XIII on page 74). Part of the increase was due to the 1977/78 winter being the most severe for several years.

These adverse weather conditions, followed by an unsettled spring and summer, resulted in widespread delays to building work. This led to a record number of enquiries from building contractors seeking details of past weather conditions to support claims for extensions of their contracts. Legal and insurance enquiries were also numerous, particularly with regard to motor and other accidents occurring in the wintry weather.

The blizzard in Scotland on 28/29 January, in which a number of lives were lost, was the subject of a special study by the Edinburgh office. The Highland Regional Council and the Scottish Development Department were provided with relevant data and an assessment of the likely probability of recurrence of an event of similar severity, based on analysis of past records. In Northern Ireland the recent series of dry summers has been of considerable concern and weekly rainfall bulletins were issued to the Northern Ireland Water Data Unit at Stormont in connection with water supplies. The close co-operation of the Belfast office with the Water Services in Northern Ireland works well, and has led to the improvement and rationalization of the climatological observing network there.

The broad range of enquiries included many requests for temperature and humidity data for the design and operation of heating and air-conditioning installations, and for extreme wind speeds for the calculation of wind loadings on buildings and structures such as radio towers and bridges. The local climate can be important in choosing a site and information was supplied in connection with petrochemical developments in Scotland.

Enquiries are also received concerning the climate of countries overseas and some 1500 were handled in 1978, mostly from consulting engineers and architects in the United Kingdom engaged in the design of new buildings and public works abroad, especially in Iran, Saudi Arabia, the Gulf States and Nigeria. Information was regularly sought on extreme winds, for which data have been

extracted and analysed for about a hundred overseas countries, and on temperature and humidity.

Marine climatology

As indicated earlier, interest in this field has been growing rapidly. This is particularly so in connection with aspects of weather significant for the design and operation of offshore installations around the British Isles. However, the scope of applications is much wider, covering such activities as the extraction of energy from wind and waves, the computer simulation of operations on tanker routes and the assessment of collision risks at sea in poor visibility. Advice and information has been supplied for many areas world-wide including the coast of South America, the Gulf of Oman, the Adriatic and the South China Sea. An essential basis has been the development of extensive archives of marine weather data and a range of computer programs to process these data. This enables advice to be given on expected wind and wave extremes, the frequency of adverse weather and so on. The facility to respond rapidly to clients' detailed requirements was demonstrated at the Oceanology International 78 Exhibition in Brighton with a terminal linked to the Meteorological Office computer.

With the increase in demand for services, opportunity for research work was limited. The marine climatologist prepared a detailed report for the UK Offshore Operators' Association (UKOOA) analysing the environmental conditions measured from March 1973 to February 1976 at the Stevenson Station (61° 20′ N, on the Greenwich meridian). The operation of this and other such stations is valuable in providing almost continuous records of observations at fixed points, but the value can be overestimated in climatological studies because the relatively short periods covered may not be representative of long-term conditions. The marine climatologist also participated in two working groups of the World Meteorological Organization (WMO), and on National Committees on offshore installations, sea defences, and safety and pollution. He was involved with the organization of a scheme for international exchange of ocean current data, the United Kingdom having been designated by WMO as the world collection centre.

Operational and climatological work on sea ice continued throughout the year. Daily charts were disseminated by radio-facsimile broadcast and monthly charts for the northern hemisphere were published for climatological and research purposes. Advice on sea-ice matters was given, for example, for ship routeing and expedition planning. The sea-ice and ocean-current sections of the Admiralty *Pilots* are continually kept under review and three volumes were revised in 1978.

Publications

The *Monthly Weather Report* is the main outlet for the publication of climatological data for the United Kingdom, and its preparation requires considerable care and effort. Possible changes in the method of production are being investigated to improve the quality and achieve earlier production. The *Snow Survey of Great Britain* is another regular publication and the format was improved in the 1977–78 issue. All the data for Part I (North America) of *Tables of*

Temperature, Relative Humidity, Precipitation and Sunshine for the World have been extracted and processed. The onerous and painstaking task of preparing the African volume was started, about a quarter of the required data having been extracted.

The introduction of a simple descriptive account of severe weather events of the past for schools in Scotland to assist with project work for Higher Grade Geography proved successful with almost a thousand being distributed last year. In addition an attractive booklet on Scotland's climate is awaiting publication and should be of particular interest to schools and the tourist industry.

Detailed statistical analyses and summaries of the upper-air observations from the UK radiosonde stations have been in abeyance for many years but the first of a new series, dealing with observations from Stornoway from 1961–70, was completed and is awaiting publication. The opportunity was taken to revise the statistical methods used to compute the various parameters and to present the data in a way that gives the maximum possible amount of useful information. The tables were produced by computer and thus the production of subsequent parts of the series dealing with other Meteorological Office stations at home and overseas can follow quickly.

One new departure has been to make climatological information available to users of the Post Office viewdata system called Prestel. At present the climatological data covers temperature, rainfall and sunshine month by month for about 100 stations around the world. The system is in an early stage, and expansion to include more information of this type is expected.

Climatological research

One of the problems in climatology is the assessment of climate at a particular location using observations from surrounding stations some distance away. A simple approach may provide misleading information as local topography, terrain and exposure are important factors. A much denser network of stations would clearly improve matters, but research into understanding more fully the effect of local conditions on climatological variables is also desirable. The Climatological Research Group continued to investigate this problem using statistical techniques to form characteristic patterns of, for example, daily minimum temperature and then clustering the stations into groups. This method enables an assessment to be made of the quality and representativity of each station, and could be useful in extending quality controls. Another approach was to attempt to isolate and then quantify the effects from certain physical parameters, like altitude. A study to determine the optimum number of years on which to base estimates of temperature in the future was completed.

The Building Climatology Section is also engaged in applied research, and continued to investigate practical problems of direct concern to the building industry. The main weather element in the loss of building production is rain. The amount of time during the working day in which rain is heavy enough to prevent outside work was found for 25 locations in the United Kingdom and analysed month by month. Different criteria for the rate of rain are required for different building processes. Maximum winds for design purposes are also very important, and amongst other work the section studied the gales of 11/12 January which proved to be the major storm of the winter. Apart from damage

caused directly by the wind, sea walls were breached and widespread flooding occurred in east coast districts. A report of this event was prepared with emphasis being placed on the significance of the winds, which proved to be in line with current building design standards. This is one of the topics also dealt with by the land climatologist in connection with his work for the British Standards Institution.

Services for Hydrometeorology

Since the Directorate of Services' Special Topic in this *Report* is devoted to work in the field of hydrometeorology over the last decade, it is not intended to present here more than a brief account of the activities in 1978.

Rainfall data were collected, subjected to quality control, and archived, as in previous years. The Bracknell office holds the complete archive for the whole of the United Kingdom, whereas the offices in Edinburgh and Belfast hold those for Scotland and Northern Ireland respectively. Most of these data, which refer to daily and monthly accumulations of rainfall, were obtained from co-operating authorities and individuals. The Office continued to take its established long-term view towards the acceptance of all such data which have been obtained in a scientifically acceptable way into the archives, and co-operation with authorities who require such data for their own operational and planning purposes has been fostered by a healthy two-way exchange of information.

The computer-based index of rainfall observing stations (known as 'Rainmaster') was extended during the year by the addition of information concerning more stations which were in operation at some time in the past as well as by the inclusion of additional information concerning some recording rain-gauges. The mix of computer-based and manual procedures for the quality control of rainfall data was further improved. These procedures are necessary to correct a minority of suspect or incomplete observations. The modifications made to the quality-control methods led to the streamlining of the manual procedures which were giving rise to a backlog of work. They were also necessary to deal with the observations made during periods of heavy snowfall in the winter of 1977/78. The occurrence of widespread heavy snowfall places particularly severe demands on quality-control procedures and skill since in such conditions a large percentage of the observations are either suspect or actually missing. A wide synoptic view coupled with skilled judgement is necessary in such circumstances. It was found that the use of a series of computer-drawn maps produced in steps under the control of a human analyst contributed significantly to a satsifactory assessment, both of widespread heavy snowfall and of rainfall events.

The extraction of rainfall information from daily autographic charts continued during the year. About 600 000 charts have now been processed, 250 000 being from an extensive network maintained by the Greater London Council. Some of the data thus extracted were used in investigational work concerned with storm drainage system design. Automatic magnetic tape rainfall event recorders were deployed in the more remote areas, particularly in Scotland and northern England, where observations are particularly difficult to obtain by traditional means. Some of these recorders were used in special survey work.

Rainfall observations were published in the *Daily* and *Monthly Weather Reports* and the earlier annual publication *British Rainfall* was replaced by a new publication entitled *Monthly and Annual Totals of Rainfall for the United Kingdom.* Maps of the annual average rainfall for the period 1941–70 for the British Isles became available during the year.

The total number of hydrometeorological enquiries received in 1978 was less than that of 1977 owing to a fall in the number of requests for simple information, often received and answered by telephone. However, the apparent decrease in work was more than offset by an increase in the number of more demanding written enquiries, some of which required special data processing. A suite of computer programs is available which enables tabulations to be produced of rainfall totals or intensities in specified durations (from 1 minute to 25 days) which may be equalled or exceeded for a range of return periods extending from as often as twice a year to as seldom as once in 1000 years. Such information can be provided for any national grid reference location in the British Isles. These, and similar programs, were used extensively to answer questions from engineers designing urban drainage systems. Much time was spent on work commissioned by the Water Data Unit of the Department of the Environment and work continued on a long-term contract placed by the Central Water Planning Unit to provide estimated monthly and daily rainfalls over a number of catchments for periods extending well back into the 19th century.

A number of enquiries for weather balance information concerned interests outside the usual areas of application. Examples included the use of such data in the study of the cause of gas pipe fractures, the interpretation of aerial photographs in archaeological work, and investigations concerning past climate, which involved the study of tree-ring features. Work continued on the preparation of a special series of historical meteorological data to aid the mapping of droughts in the past and the combined frequency analysis of rainfall and estimated actual evaporation.

One of the more important developments in 1978 was the inauguration in April of the output from MORECS (Meteorological Office Rainfall and Evaporation Calculating System) as a routine service. This is a major extension of the bulletin *Estimated Soil Moisture Deficit and Potential Evapotranspiration over Great Britain* which has been available at fortnightly intervals since 1962. MORECS is a weekly advisory service available on a commercial basis.

Not infrequently the Office is asked to provide hydrometeorological advice relating to overseas countries, especially when British companies undertake constructional work abroad. From time to time demands for much wider investigations arise and a scientist was detached to work in South Korea in 1978.

The measurement of rainfall by radar commenced in south-west England. Although these measurements were primarily intended as an aid to short-period weather forecasting, substantial implications arise from rain-gauge network design, methods for the quality control of observations and data archiving systems. The incidence of two simultaneous views of the rainfall field (by radar and rain-gauges, neither of which can be absolute) should lead to better determination of point and aerial rainfall amounts than have been available hitherto. Work commenced on methods of synthesizing these two types of data.

The study of hydrometeorology of forests continued in co-operation with the Institute of Hydrology, where a small Meteorological Office team is located.

Measurements were undertaken at sites in Northumberland and Wiltshire, and mathematical models of the water balance of such areas were tested, the aim being to develop methods of estimating the influence of afforestation on water resources. Co-operation on hydrological matters continued at the national and international level.

Services for Agriculture

Staff at four small meteorological units attached to regional headquarters of the Agricultural Development and Advisory Service (ADAS) provide a direct meteorological service to agriculture in England and Wales. A unit at Edinburgh maintains a similar service for Scotland in conjunction with the Scottish Colleges of Agriculture. At Bracknell a headquarters group provided support to these outstations, for example, by supplying processed climatological data from the data banks of the COSMOS computing system.

A very wide range of work was again undertaken during the year. The main preoccupation of staff at the outstations continued to be the provision of rapid solutions to a variety of problems within agriculture. Much of this work was done in close collaboration with counterparts in ADAS. The solutions often require only straightforward applications of existing weather data, but sometimes the meteorologist finds himself in the role of an environmental physicist in dealing with the more complex problems. At Bracknell a substantial effort was devoted to producing routine information on weather likely to favour the spread of various crop diseases. These routine data were sent daily to plant pathologists in ADAS and the Scottish Colleges and in particular to the Plant Disease Intelligence Unit at ADAS Bristol which has responsibility for monitoring the level of diseases in field crops throughout England and Wales. During 1978 improvements were made to this service and there were additions to the number of diseases for which a weather alerting procedure is operated. A routine service introduced during the year was the supply of weekly estimates of soil moisture deficits under various crops to a number of ADAS recipients, together with values of actual and potential evaporation.

Solutions to some of the problems tackled by the outstations again required field measurements of weather variables. In this context a number of studies were made of various aspects of shelter, using arrays of anemometers. The problems examined included the use of shelter to reduce wind damage to glasshouses and their fuel costs, applications of artificial and natural shelter in orchards and around horticultural plants, and the deaths of unweaned lambs from cold and wind that might perhaps be avoided given more effective shelter in the field. Investigations were also made of conditions in calf and pig houses.

Improvements in the service provided to agriculture continued to depend heavily on the application of results from more fundamental investigations within the science of agricultural meteorology, which again comprised a substantial part of the activities at outstations and of the support group at Bracknell. A number of studies were commenced which explore one of the central problems of agriculture—the relation between yields of crops and weather. Among these are grassland production in relation to water supply, the estimation of yields of spring barley and forage maize by calculation of the carbohydrate balance of these crops, and the quantitative relationship of

national cereal yields to simple weather elements such as temperature and soil moisture deficit. Work on delineating areas of Britain suitable for maize growing was completed during the year. The role of a number of weather factors in the incidence, on a national scale, of *Septoria* disease of wheat was assessed, whilst a multi-layer model of crop canopies was devised which, it is hoped, will improve the estimates of the occurrence of environmental conditions known to be critical to the spread of some fungal pathogens. A detailed model of potato blight disease response to weather factors was constructed using laboratory data and tests using past field data were started. Results of an investigation in 1977 on eyespot disease of winter wheat were incorporated into the routine issues of plant disease warnings. Entomological problems tackled include the timing of aphid infection on potatoes, cereals and vegetables in Scotland, a project begun which aims at predicting the likely severity of cutworm attacks and the best time of application of insecticide sprays. Plant growth is strongly dependent on water supply and this topic continued to be actively investigated. Too much water can be as detrimental as too little and it is appropriate that support continued to be given to ADAS in their drainage experiments on soils prone to winter waterlogging. Water balance sheets were constructed for 130 sites in England and Wales where ADAS are attempting to elucidate the effects of different drainage treatments. A guide for day-to-day irrigation planning was completed in association with ADAS. Work began on a new edition of the MAFF *Technical Bulletin* on irrigation. Further effort was devoted to problems of the soil water balance under grass and arable crops, with the help in some cases of neutron probe observations of soil moisture (the instruments provide an independent method whereby results may be compared with meteorological estimates of soil moisture deficit).

A system of rainfall forecasting first tested in 1976 and designed to give farmers useful guidance for up to three days was modified slightly and underwent further trials during the summer with the help of other branches of the Office. Results from these trials, and from another forecasting experiment to predict potential rates of drying of cut grass up to three days ahead, were assessed. New projects connected with animal production involved comparisons of hill climates of Wales and Scotland in relation to sheep farming and the search for weather effects in outbreaks of Aujessky's disease of pigs. Studies of the weather dependence of parasitic gastro-enteritis continued. Further progress was made in delineating areas with broadly uniform climates for agricultural purposes in Scotland.

Much of the work of the Branch again benefited from active collaboration with a variety of other institutes including MAFF Central Veterinary Laboratory, Plant Pathology Laboratory, the Agricultural Research Council Letcombe Laboratory and Grassland Research Institute, and many university departments.

A display prepared for the Royal Agricultural Society of England Show in July, and manned in collaboration with staff from the London Weather Centre, attracted much interest. The Show also provided an opportunity for distributing copies of a new brochure 'Services for Agriculture', which describes operational, advisory and research activities of the Meteorological Office in agriculture. Part of the display was a film 'Weather for Farmers' made by the BBC, which reported some of the Branch's activities.

A large number of lectures were given by members of the staff during the year to ADAS groups, colleges, farming societies and similar organizations. A

two-day course on agricultural meteorology for senior ADAS staff was also organized at the Meteorological Office College.

Observational Requirements and Practices

The Branch, of which the Marine Division under the Marine Superintendent is a part, has overall responsibility for arranging that regular meteorological observations of suitable quality are made on land, at sea and in the upper atmosphere in sufficient numbers and with an appropriate distribution in time and space to meet national and international requirements. It specifies how meteorological sensors and observing systems shall be exposed and details the observing techniques to be employed. It arranges for observing stations to be inspected regularly to ensure that approved standards of site, instrumentation and observational procedures are maintained. The Branch establishes, on behalf of the forecasting, climatological and hydrometeorological branches, requirements for new or improved sensors, observational systems or practices and organizes field trials to determine suitability for operational work, optimum procedures for their routine use and the effect of their introduction on the accuracy and comparability of the basic observational data. It works closely with the Operational Instrumentation Branch on the specification of new sensors or observational systems and on the design of trials to establish the performance of prototypes.

The Branch provides the Chairman and Secretary of an internal working group concerned with reviewing the UK Observational Networks; the working group has produced important policy statements on networks of synoptic, climatological and automatic weather stations and is currently preparing a similar statment on marine networks. In the international field the Assistant Director (Observational Practices) serves on the World Meteorological Organization (WMO) Working Group on the Global Observing System (GOS) and attended the seventh session of the WMO Commission for Basic Systems. Senior Branch members serve on WMO Working Groups concerned with radiation measurements and with the compatibility of data obtained from different upper-air measurement systems as well as on the Advisory Working Group of the WMO Commission for Instruments and Methods of Observation.

Observatories

The Observatories at Kew and Lerwick and the Meteorological Office section at Eskdalemuir (a NERC Geomagnetic and Seismological Observatory) continued to make a wide range of observations of the highest quality. In addition, Lerwick continued to be a WMO 'base-line' station for atmospheric pollution studies. The three Observatories also provided valuable facilities for the impartial testing of new or improved instruments and observing techniques.

The program of work at Lerwick is the most extensive of all and observations were made of ozone, noctilucent clouds and aurora and certain chemical constitutents of air and rain. Solar radiation observations and upper-air soundings continued and a full program of thunderstorm direction finding as part of the UK network was also undertaken.

During 1978 new equipment for recording atmospheric potential gradient was installed at all three Observatories to replace equipment which had reached

the end of its useful life. The opportunity was taken to add continuous recordings of air–earth current to the program of work.

Surface observations

Several different kinds of surface observations are made to meet particular requirements. For weather analysis and forecasting purposes a network is maintained, consisting of observing stations making weather reports at fixed times agreed internationally. It is essential that such reports, known as 'synoptic' reports, should be received without delay. At the end of 1978 the United Kingdom synoptic reporting network consisted of 264 stations, of which 82 made hourly reports and 50 made 3-hourly reports throughout each day of the year. The remaining 132 stations reported less frequently, some closing at night or at weekends. Meteorological Office staff manned 82 synoptic reporting stations, most of which were located at civil and military airfields. The remaining 182 stations were manned by staff of various other authorities and organizations, such as coastguards and lighthouse keepers or by private individuals, these stations being known as auxiliary reporting stations. Special courses for training auxiliary observers in the making and reporting of weather observations were held at the Meteorological Office College. When it was not possible for an auxiliary observer to attend one of these courses, arrangements were made for instruction to be given at a nearby meteorological office, or a member of the staff of the Office visited the auxiliary reporting station and gave instruction on the spot.

There is also a requirement for records of meteorological variables to be maintained over long periods at sites representative of the various types of terrain and urban environment. These 'climatological data' provide information for the long-term averages, extreme values and frequency distribution of meteorological variables and are used in a variety of planning activities notably in agriculture, town planning and industry. It is, of course, important that the exposure of climatological stations should remain substantially unchanged for long periods and this is becoming increasingly difficult to ensure.

Many stations making synoptic reports submit climatological returns as well, usually for several observing hours each day. At a number of key climatological stations manned by Meteorological Office staff these returns covered the whole 24 hour period. About 500 other stations made climatological returns only, usually of data read at 09 GMT, though some made returns for additional hours. Most of these stations were operated by local authorities or similar organizations but a number were still operated by private individuals on a voluntary basis at their own expense. Courses for climatological observers were held at the Meteorological Office College. Inspections of both synoptic and climatological stations were carried out regularly.

For rainfall, a more extensive network is required to provide the data needed to determine the distribution. This information is of great value for water use, control and planning. Data were received from about 6500 stations most of which measured rainfall only, 69 having magnetic tape event recorders. The majority of rainfall stations were maintained by co-operating authorities, usually Regional Water Authorities, the remainder being operated by a variety of other authorities and by private individuals. The Meteorological Office collected data from all rain-gauges that met suitable standards of exposure and

equipment and carried out an inspection program to ensure that these suitable standards were maintained. In previous years the rate of inspection of rainfall stations had fallen well below that which is desirable. The number of inspecting staff was therefore increased and visits to stations were made more frequently. However, the time interval between inspections at most stations was still about 4 years.

In order to assist the forecasting of weather conditions along major roads a network of 70 stations provided plain-language reports of current weather. Most of these were located at road maintenance depots alongside motorways and at Automobile Association and Royal Automobile Club offices. Reports were made at approximately three-hourly intervals during daylight hours throughout the year and also during the night in winter months. These stations were inspected regularly.

Lengthy trials showed that automatic weather stations are now sufficiently reliable and accurate to be used to supplement the surface observing system. They cannot yet give the wide range of observations provided by the human observer but they provide the only means of gathering synoptic data from areas, or at times, where it is difficult or unduly expensive to support human observers. Five automatic weather stations were installed and brought into operation and plans were made to install 28 others to respond to the initial phase of the proposals of the Working Group on UK Observational Networks.

Observations are required to support the specialized forecasting service given to the offshore industry. An automatic weather station was installed at Muckle Holm, the island on the approach to the oil terminal at Sullom Voe in the Shetlands, and progress was made with the installation of three new auxiliary stations to help with forecasting weather for the operation of large tankers in the Sullom Voe. Automatic weather stations were also installed on oil platforms in the North Sea and on a buoy in the south-west approaches. Advice was given to the offshore gas and oil industry on meteorological instrumentation and observational procedures. One officer was based at Aberdeen and dealt with installations within the United Kingdom offshore area north of latitude 55° N. A second officer was based at Bracknell and dealt with installations south of latitude 55° N. The major effort was directed towards obtaining regular good quality observations from the fixed production platforms for both synoptic and climatological purposes although advice was also given to the more transitory drilling rigs. Both officers worked closely with the London Weather Centre. Courses for observers from offshore structures have been held at the Meteorological Office College.

Radiation observations

There is a long history of solar and terrestrial surface radiation measurements in the Office, notably at Kew Observatory, but it was not until the 1950s that systematic observations were made at a number of stations. At the end of 1978 the United Kingdom official network consisted of eight stations. The last overseas station for which the United Kingdom was responsible, Malta, closed in July. Problems with new data logging equipment (MODLE 3) impeded progress on commencing radiation measurements at six radiosonde stations.

At the end of 1978 there were 25 co-operating stations operated by authorities having a hydrological or agricultural interest. These provided data, mainly in

the form of daily totals, for which the Office operated quality-control procedures. Regular liaison visits were made to these stations and the Office offered an instrument calibration and repair service with the object of securing homogeneous data throughout the network.

Studies continued of methods of deducing the radiation climate at locations at which observations are not made. The observational phase of an experiment to test the predictions arising from these studies, involving a dense array of 10 autographic radiation stations, was completed. Good progress was made with preparing a radiation climatology of the United Kingdom consisting of tables and maps of radiation for the ten-year period ending 1975.

Reliable radiation measurements of suitable accuracy can only be achieved by daily attention to instruments, by frequent calibration of recording equipment and comparison of instruments against secondary standards. The secondary standards have to be compared regularly with the national standard which has been an Ångström pyrheliometer for many years. The standard instrument and the Office's cavity absolute radiometer were taken to Carpentras in southern France in June for an international intercomparison of national standards.

National and international interest in aspects of obtaining energy from solar radiation continued and the branch was active in the WMO Regional Association VI Working Group on Solar Radiation, the European Economic Community Solar Radiation Data Acquisition Group and in an International Energy Agency Solar Energy Program group.

Many enquiries from universities and industry were answered.

Runway visual range

At many airfields Air Traffic Control staff or other non-meteorological staff assess the 'runway visual range' in poor visibility with the aid of lights at known distances. The Meteorological Office provides a service of inspection and calibration of these installations for the Civil Aviation Authority and the Royal Air Force. The calibration is necessary to establish the relationship between the number of 'RVR reference lights' the observer can see and the distance along the runway the pilot of an aircraft can see from the 'touch-down zone'. Twice-yearly visits were made to 32 civil airports in the United Kingdom and to 35 RAF stations at home and abroad.

Upper-air observations

The normal program of upper-air observations comprises pressure, temperature and humidity soundings by radiosonde at 00 and 12 GMT and upper-wind measurements by radar at 00, 06, 12 and 18 GMT. This program was maintained by eight stations in the United Kingdom and overseas at Malta and Gibraltar.

A new automated radiosonde (Mk 3) system was successfully introduced at all eight UK stations during the year. Preliminary analysis of the results indicated a performance considerably better than that of the old (Mk 2b) system and indeed of other designs in use round the world. The performance in operation closely approached that obtained in trials of initial models of the Mk 3 sonde.

The two weather ships—the *Admiral FitzRoy* and the *Admiral Beaufort*—were deployed alternately at North Atlantic Ocean Station 'L' (57° N, 20° W). They

carried equipment which made use of radio transmissions provided for navigation purposes in order to determine winds aloft and in this way the engineering and financial problems associated with the provision of wind-finding radars for use at sea were avoided. The upper-air program in the ships was increased during the year to four complete (temperature, humidity and wind) soundings per day.

Close liaison was maintained with the International and Planning Branch which has established upper-air stations overseas as part of the UK contribution to the World Weather Watch program. One of these stations, at Mahé in the Seychelles, was the subject of a visit of inspection.

The performance of high-altitude balloons continued generally to be good, with 30 km being regularly attained. However, some deterioration was observed in severe weather conditions in the Shetlands during the winter of 1977/78. Performance of the regular balloons apparently deteriorated somewhat but this might have been the result of more accurate altitude determinations by the new automated system. Once again, the performance of neoprene balloons showed a significant improvement over that of balloons made of natural rubber.

Thunderstorm location and surveillance

A full program of half-hourly observations by day and hourly observations by night was maintained throughout the year by the network of direction-finding stations at Lerwick, Shanwell, Camborne, Hemsby, Gibraltar and Malta.

The total number of storms located during the year was again less than in previous years. This was in part due to a reduction in the area covered arising from the loss of Cyprus as a direction-finding and flash-selecting station. There has been a continuing downward trend in the number of storms located over the last 12 years. It is not known whether this trend reflects a climatological change or arises from changes in instrumental performance or operational technique. The station at Malta closed on the last day of the year and its loss is expected to reduce further the area covered and to degrade the accuracy of storm location, particularly over Spain and Portugal.

User trials of new equipments

Following the development or procurement of new sensors or equipments, field trials were carried out throughout the year to determine the quality and reliability of these devices from the user's point of view. The performances of various types of digital temperature indicators, meteorological marine buoys, other forms of automatic weather stations, new thermometer enclosures, rain-gauges and a mean wind-speed indicator were examined.

The Office planned to obtain experience with a new equipment known as ASDAR (Aircraft to Satellite Data Relay), two of which were obtained on loan from the US National Oceanic and Atmospheric Adminstration. Plans have been prepared by British Airways to install the equipment in two of their Boeing 747s. Every eight minutes during flight ASDAR will transmit via a satellite to a data-collecting centre measurements of wind, temperature, height and position, and this information will immediately be relayed on the Global Telecommunication System.

Marine Division

The depressed state of the shipping industry has resulted in the withdrawal from service of a number of older vessels from the British Merchant Navy Fleet. The trend has been to replace small conventional tonnage with larger, faster container vessels which spend more time at sea than their predecessors. Therefore, although the strength of the Voluntary Observing Fleet (VOF) decreased marginally during 1978, the number of observations received continued to increase. The responsibility for recruiting vessels into the VOF devolves upon the seven Port Meteorological Officers at London, Liverpool, Southampton, Hull, Newcastle, Cardiff and Glasgow and it is a measure of their effectiveness that the strength of the VOF has been largely maintained despite the recession. Being master mariners with considerable experience as voluntary observers at sea, they are also able to contribute significantly to the maintenance of a high standard of observations received from the VOF. Meteorological work at sea in British Merchant Ships has always been carried out on a voluntary basis and it is gratifying to note that the standard of observing throughout the year has, in general, been well maintained.

The liaison work between the Port Meteorological Office staffs and the various shipping companies was of mutual benefit. The installation of distant reading meteorological equipment and automatic weather stations in a number of merchant ships under construction, in order to ease the workload of observing officers, continued with the whole-hearted support and co-operation of shipowners.

In 1977, a set of basic meteorological instruments and stationery was supplied to a number of yachts competing in the Whitbread Round-the-World Race. The Race was completed during March and April 1978 and, once again, arrangements were made for special forecasts and warnings to be broadcast from Portishead Radio each day whilst the yachts were between the Equator and the United Kingdom.

Once again, acknowledgement must be made to the many Commonwealth and foreign Port Meteorological Officers for their valuable services and assistance in the replacement of defective instruments in UK Selected Ships on protracted voyages and the withdrawal of instruments from British ships which have been sold abroad.

As in previous years, 'Excellent' awards in the form of books were made to the shipmasters, principal observing officers and radio officers who were responsible for submitting the 100 best meteorological logbooks for the year. Similar awards were made to masters and officers on the short sea trades for their contribution in making sea temperature observations and also to skippers and radio officers serving in trawlers with the best records in making and transmitting non-instrumental observations. Long-service awards in the form of barographs were made to four shipmasters in recognition of their valuable voluntary meteorological observing over many years during their careers at sea.

The *Marine Observer*, a quarterly journal of maritime meteorology, the object of which is to stimulate the interest of mariners in marine observing, has been published quarterly as hitherto and continues to be well received.

Marine enquiries, principally from shipping interests, solicitors, universities and industrial firms, continued at a high level. The subjects of the enquiries were extremely varied and, this year, have ranged from the weather conditions

prevailing at the Battle of Taranto in 1940 to those experienced during and after the stranding of the super tanker *Amoco Cadiz*.

The United Kingdom continued to operate two Ocean Weather Ships within the North Atlantic Ocean Station (NAOS) scheme. The ships, the *Admiral FitzRoy* and the *Admiral Beaufort*, continuously manned station 'L' at 57° N 20° W throughout the year with the exception of a 5-day period during March when the *Admiral Beaufort* vacated the station to land an injured crew member and a 20 hour period during October when *Admiral Beaufort* was forced to vacate the station prematurely owing to shortage of fuel. Additionally, the *Admiral FitzRoy* had to vacate station for a few days during November to land one of her senior officers who had suffered a suspected cardiac condition.

The weather ships make hourly surface and 6-hourly upper-air observations (for heights reached in upper-air ascents see Table V on page 70). Reports of floating pollutants for the Intergovernmental Oceanographic Commission/World Meteorological Organization pilot project on marine pollution monitoring together with sea and swell records using the Tucker shipborne wave-recorder were continued throughout the year. Sea-water temperature and salinity readings to considerable depths, collection of rain-water samples for analysis by the International Atomic Energy Agency, observations of magnetic variation and collection of sea-water samples on passage to and from station for monitoring radio-active content were undertaken at regular intervals.

Operational Instrumentation

The Branch is responsible for meeting the needs of the user branches for meteorological instruments and data-acquisition systems. The requirements of the forecasting, climatological and hydrometeorological branches are examined in close co-operation with the Observational Requirements and Practices Branch, and either the most suitable system composed of existing sensors and data-acquisition modules is chosen, or an Operational Requirement defining the need for a new development area is raised. The necessary design, development and/or adaptation of equipment required to meet the application is then carried out. When prototypes and pre-production equipments have successfully passed their trials, or suitable equipment is already available commercially, manufacturing contracts are placed for a production quantity of equipment. The Branch is then responsible for the technical progressing of the contract, for acceptance testing and calibration of the equipment on delivery, for planning and installation in the field and finally for maintaining and servicing the equipment on the outstations and for making subsequent 'post-design' modifications throughout its life.

The first operational flight of the Mk 3 radiosonde was at Aughton in November 1977. During 1978 the conversion of the routine sonde stations to the Mk 3 system continued and further stations started operational flights as follows: Crawley and Hemsby (March), Camborne (April), Long Kesh (June), Shanwell (July), Stornoway (September), and Lerwick (October). The installation at Lerwick completed the conversion of the routine network of the upper-air stations covering the United Kingdom.

The Mk 3 radiosonde ground station computer program, in its routine form, is not completely satisfactory for the four Army and Procurement Executive

stations which fly sondes for experimental purposes. A contract was let to study the minor hardware and software modifications which are necessary to provide the information which these stations require. When implemented, the enhancement will improve the height resolution of the wind data and the software will include an acoustic ray tracing program to aid in the prediction of acoustic 'focusing' of explosions, or gunfire, which can cause annoyance or damage to local households.

The Mk 3 radiosonde central calibration facility produced calibrated transducers for the operational network throughout 1978. Difficulties during the final acceptance testing held up the handover of this facility to the Office until late in the year. At maximum capacity the calibration plant can calibrate 550 pressure units and 550 pressure reference units per week.

The development continued of an experimental system for locating lightning flashes by using the Arrival Time Difference principle. Hardware was produced in order to measure, time and record accurately the arrival of electro-magnetic wave forms caused by lightning flashes. Two field trials were conducted during the latter part of 1978. The first used equipment placed at four widely separated locations in the United Kingdom; the second used equipment at three United Kingdom sites and at Gibraltar. Software was developed in order to analyse the recorded data and a start was made with the analysis. Since these trials were held in a period of low thunderstorm activity it is hoped to carry out further experiments when thunderstorm activity is expected to be higher.

In January 1978 it became apparent that a special forecasting service would be required to support the new oil terminal which was being built at Sella Ness/Sullom Voe in the Shetland Islands (see page 42). As part of this service it was necessary to produce and install an automatic weather station at Muckle Holm, a small island in the estuarial waters of Yell Sound (see Plates II and III). Measurements of temperature, humidity, winds and visibility were transmitted via a VHF link to the oil terminal Control Room at Sella Ness. The data were also made available via a Post Office subscriber trunk dialling (STD) line to Lerwick Observatory and London Weather Centre. Planning for this installation began in February, and by dint of excellent co-operation between all the branches involved, the Post Office and the Shetland Islands Council, the installation was completed and the system became operational on 1 October 1978.

Co-operative projects: international

The Branch was involved in two projects under the European Economic Community Scheme for co-operation in Science and Technology (COST) during 1978. COST Project 72 deals with the standardization of meteorological instruments within Western Europe, but progress was slow in this area. The United Kingdom made proposals concerning the possibility of setting up a European weather radar network on the principle of using standard interfaces and data format for the various national schemes and linking them across the national borders. A senior officer of the Branch attended two meetings of the Technical Committee during the year.

The project concerned with a European network of oceanographic/meteorological data buoys (COST Project 43) made a large step forward when the international Agreement defining a 4-year experimental pilot project was signed late in 1977. An interim Management Committee was set up, on which a

senior officer of the Branch serves as Vice-Chairman, and meetings were held in February, May and December. As part of the UK participation in COST 43 a joint co-operative trial and comparison of a Norwegian buoy and a United Kingdom buoy was arranged. This involved participation by the Norwegian Christian Michelsen Institute, the Department of Naval Oceanography and Meteorology (DNOM) and the Meteorological Office. It had been hoped to commence this trial (to be located at 59° 30′ N, 06° 00′ W) in the Autumn of 1978, but this was not possible owing to delays in the production of the buoys in both countries.

Co-operative projects: national

Following discussions at meetings of the Standing Committee on Ocean Data Stations at which two senior officers of the Branch participated, the Meteorological Office was asked to reconsider its policy with regard to future plans for Ocean Data Acquisition Systems (ODAS) in the continental shelf waters off the United Kingdom. A study of this matter by the internal Working Group on UK Observational Networks commenced.

The effort aimed at placing a number of automatic weather stations (AWS) on oil platforms in the North Sea continued. The installation of meteorological sensor suites was completed satisfactorily on Mobil's Beryl A platform and Occidental's Piper A platform. The completion of these installations by the addition of a micro-computer-based data processor and transmission system was delayed until the end of the year owing to difficulties in obtaining access to the platforms due to technical and administrative problems. Approval was also given later in the year for the placing of a third AWS on the Amoco 49/27A production gas platform. The data from these AWS will be used in support of the members of the United Kingdom Offshore Operators Association (UKOOA) with whom the Office has close contact.

The 8 ft diameter toroidal wave-rider buoy (ODAS 1), which had been deployed in Lyme Bay in 1977, had some operational problems early in 1978. However, since redeployment in July, it has been operating satisfactorily. A modem link was installed permitting interrogation on demand by London Weather Centre.

Branch participation in the UK Data Buoy Project (DB1) continued (see Plate III). This project was led by the Seatek Consortium with support from the Department of Industry, UKOOA, the Institute of Oceanographic Sciences (IOS) and the Meteorological Office. A duplicate suite of meteorological sensors and associated electronics was installed early in the year, and in June 1978 the buoy was deployed 160 miles south-west of the Scillies. Officers of the Branch were involved both in the buoy deployment, and in the arrangements whereby the receiving station was installed at Culdrose. Data were transmitted hourly via this shore station to the Seatek centre at Woking. London Weather Centre and other suitably equipped offices could access the meteorological data by a Post Office STD 'dial-up' facility.

The installation of an automatic weather station on the Whitaker Beacon off the Essex coast was delayed, but modifications to the tower structure in order to accommodate the equipment were completed by Trinity House. Other negotiations with Trinity House resulted in their agreement, in principle, to a plan to instrument three of their large Navigation Buoys (LANBYS) with AWS equipment similar to that used on the buoy in Lyme Bay.

A further joint project involves the installation of additional meteorological sensors on the National Maritime Institute (NMI) tower at Christchurch Bay, and negotiations were successfully concluded.

Development, production and evaluation of new instruments and systems

The two refurbished ocean weather ships were equipped with fully operational NAVAID wind finding equipment when they sailed on their maiden voyages, as reported last year. A third system, modified to meet the full specification prepared by the Branch in consultation with users was delivered and accepted early in 1978, and it was not until November that it was possible to complete the modifications to the two original equipments. All three NAVAID systems now meet the full operational specification.

The acceptance of twelve data-logging equipments for the radiation recording network was finally completed after some rather obscure manufacturing problems had been solved. Three were installed at Kew, London Weather Centre and Crawley and further trials were conducted at Beaufort Park. An additional four sets were ordered to meet the full network requirement and to obtain necessary spares back-up.

A contract for 20 digital anemograph logging equipments was placed and most were delivered and accepted during 1978. Approval for the procurement of a further 20 equipments was sought. These equipments, entirely designed within our laboratories, will enable the Climatological Branch to process wind data rapidly by computer instead of using laborious manual methods.

Amongst other contracts from which deliveries commenced was one for 120 digital temperature indicators. These are being obtained to replace the resistance bridges presently in use on some ships of the Voluntary Observing Fleet and they will become the standard means of measuring temperature and wet-bulb depression at land stations where the instrument enclosure is remote from the observing office.

A contract was placed for the modules required to build 19 Mk 5B wind-measuring and display systems. This is another equipment designed and developed entirely in our laboratories which has been subjected to comprehensive field trials. They will be installed at major airfields, where they will allow a greater flexibility in the distribution and display of the wind data over long distances and on many display dials and recorders.

Following the extended trials carried out on the Meteorological Office Weather Observing Systems (MOWOS), a policy decision was taken that a number of Synoptic Automatic Weather Stations (SAWS) will be required during the next decade. Approval was given for the procurement of 20 SAWS and action started to define the specification, data format and method of data dissemination. The system specified will be based on the more general development work on AWS which continued in the laboratories.

Apart from the AWS for oil platforms mentioned above, efforts continued to install four Continuous Automatic Remote Display systems at RAF and Army ranges. Successful data transmission was conducted between Theddlethorpe and Binbrook and between Wainfleet and Coningsby in Lincolnshire. However, arrangements to install further systems at the Otterburn and Sennybridge Army ranges were held up by planning, siting and communications difficulties.

Development work on automatic weather stations was mainly confined to modifying and improving the design of the micro-computer which lies at the

heart of the various AWS. However, some design studies were prepared in response to a request for a simplified micro-processor system to meet certain agro-meteorological applications. Work continued on the software for two prototype automatic climatological recording equipments and trials will start at Beaufort Park in early 1979.

Considerable effort was put into various forms of communication trials connected with the introduction of automatic or semi-automatic data acquisition and transmission systems on UK registered merchant ships. An HF/WT trial was conducted on the *CP Discoverer*, and an AWS using the RTT system was installed on the m.v. *Oroya*. A further merchant vessel, the m.v. *Oropea*, was selected for a trial of an AWS system using the METEOSAT communication system. It is hoped that these trials will lead to a system which will ensure the regular supply of meteorological data from ships of opportunity while easing the work-load on the officers and crew.

In the sensor development area the principal activity continued to be one of evaluation and trials rather than experimental manufacture. Following the extended trials of the laser cloud base recorder reported last year, approval was granted for the purchase of an initial batch of 20 instruments of this type. The full numbers needed in order to replace all the existing nodding-beam ceilometers, as they reach the end of their useful life, and to complement the existing network will amount to a total of over 120 cloud base recorders. The assessment of the trials of various visibility measurement devices was completed and a decision on future procurement is awaited. Three gravimetric rain-gauges were built to a design similar to that of the Kew gravimetric rain-gauge and comparative trials began at Beaufort Park. It is hoped that these will be used as calibration standards in the field. A decision was taken to purchase a commercial acoustic sounder in order to evaluate its potential as an aid to the forecaster by detecting the height of fog tops.

A contract was placed for a further 20 000 Mk 3 radiosondes. The opportunity was taken to include a small number of improvements which were devised as a result of experience with the initial batch.

Technical management and services

The Branch is responsible for the provision of technical services and facilities to all user branches within the Meteorological Office as well as its own development sections. This includes mechanical and electronic workshops, an engineering drawing office, the technical aspects of procurement, technical documentation, routine test and calibration, installations, maintenance and post-design and photographic services.

Activity in this area continued at a very high level although there is inevitably some variation in the load on different sections. For instance, the Engineering Drawing Office and Mechanical Workshops which for some years have been overloaded almost to breaking point, were able to consider some tasks of lesser priority. Conversely, the loads on the Electronic Workshop and on the Post Design Services groups showed an increase. Plans were made to reorganize these Sections and to increase the effort available in keeping with the increase in numbers and types of equipment which are being deployed in the field.

The increase in the types of equipment reaching the procurement stage resulted in a heavy burden being imposed on the technical liaison section. At the tendering stage, requirements have to be explained carefully to potential

manufacturers and, once a contract is placed, constant monitoring of progress is essential.

The installation section had a varied year. It brought the Cyprus weather radar back into action after the Akrotiri accident by designing, constructing and installing the necessary replacement units. Some additional work was carried out on the Camborne weather radar and a Cossor wind-finding radar was refurbished for use at Royal Aircraft Establishment, Aberporth.

Cloud Base Recorder Units were modified and installed for a special airfield requirement and the sensors on the Lichfield IBA mast which feed into an automatic weather station were overhauled and re-installed. The latter equipment, which is subjected to periodical performance monitoring became regarded as operational and the data were disseminated on the communications network. Other installations are referred to elsewhere.

There was an increase in the effort provided by the Branch in radar matters. This included the involvement of a senior officer in the definition of the requirement for the co-operative North West Radar Project and in the procurement of the system.

Co-operation with the Meteorological Office Radar Research Laboratory at Malvern and appropriate sections of the Procurement Executive, Ministry of Defence continued.

A weather radar was installed at Camborne and planning has been initiated for the installation of a further radar at Upavon. A possible site for the proposed London area radar was identified.

Proposals were received for the modernizing of the wind-finding radars. The aim is to prolong the life of the equipments for a further 12–15 years by a short refurbishment program.

The test and calibration section was particularly busy, both in dealing with the influx of new equipments and in bringing its own standard instruments up to date. Emphasis was placed on acquiring standards traceable to the national authorities such as the National Physical Laboratory. With the assistance of the development section, new, improved calibration equipment was developed and assembled for solar radiation instruments.

The Mk 2B radiosonde calibration equipment was finally shut down after 25 years continuous service (except for a short period during transfer from Harrow to Bracknell in 1962) and the staff were retrained to operate the Mk 3 radiosonde calibration plant.

The number of instruments tested and calibrated is shown in Table XV.

The facilities of the Mechanical Workshops were improved with the addition of a cutter grinding machine and a floor crane. The machines have generally been brought to a high level of efficiency. A high proportion of the work undertaken continued to be for the Research branches.

The rewriting of Part I of the *Handbook of Meteorological Instruments* made steady progress. The need to invite comments from a number of branches and individuals inevitably slowed down the process.

Technical enquiries were again numerous and covered a wide spectrum from schoolboys asking how to construct simple instruments to consultants seeking information on complete meteorological systems for foreign countries.

Plans have been made to improve the accommodation for the radiosonde calibration plant at Eastern Road, and to provide extra office and laboratory accommodation at Beaufort Park. Work has started at Beaufort Park on

building a Buoy Shelter in which buoys and other large structures can be stored and worked on during darkness and inclement weather.

Maintenance and technical training

The Meteorological Office Maintenance Organization (Met OMO) continued to improve the range of technical facilities and to widen the scope of its support for meteorological offices at home and overseas. Instruments and systems installed on oil rigs and platforms in the North Sea, on data buoys, ships and remote islands such as Muckle Holm (Shetlands) were visited as required and plans made to provide a regular service for all meteorological marine activities. Met OMO facilities for the computer-based message switching system AUTOCOM were consolidated and additional responsibilities included the microprocessor operated Ocean Weather Ship communication terminal as well as a range of modems, teleprinters and communication equipment. Close liaison was established with branches concerned with the outstation automation program, since these systems will eventually be maintained by Met OMO.

During the year responsibility was assumed for the maintenance of Mk 3 radiosonde ground stations after they had been installed, for the radar system at Camborne and, of course, other new equipments as they were installed in the field.

The increasing responsibilities of the Met OMO have called for a high level of support from Headquarters. To achieve this, efforts were made to strengthen the Headquarters team and improve the links between the development and maintenance staff. A Regional Technical Officer was made directly responsible for all overseas maintenance groups.

Technical training continued to be carried out on behalf of the Assistant Director (Professional Training). In addition to the now routine Assistant Scientific Officer/Radio (Meteorological) Technician conversion courses, which were barely sufficient to provide the numbers of technicians required to meet increasing demands in both maintenance and development, a greater number of courses have been held on specific equipments (see Table XVII). These included several courses on the Mk 3 radiosonde ground station equipment and one for microprocessor based systems. A course on a specific type of radar was held primarily for American technicians operating in the Third World, whilst training was also given to a group of students from African countries on various equipments and on test and calibration procedures as part of a longer course.

Computing and Data Processing

The Data Processing Branch is responsible for operating the main computer system of the Office known as COSMOS and for maintaining and developing the software needed for its operation, including that of typewriter and visual display unit (VDU) terminals. It is also responsible for general-purpose program storage, quality control and retrieval of observational data received in real time from the telecommunication system, and to produce plotted and line-drawn charts and graphical displays required for both operational tasks and research work. The Branch also operates the processor-controlled key-to-disc data-entry system (PCK) and the punched-card unit.

A megabyte of main memory was added to the 360/195 computer in May and two megbytes of main memory were added to the 370/158 computer in August in order to meet the growth of forecasting and climatological services over the next few years. A contract was also awarded for the supply of two disc controllers and four high-density magnetic discs with fixed-head facilities. The latter will greatly increase the on-line storage available to COSMOS and also provide dedicated fast backing store for the 370/158 computer. The award of these contracts to three separate companies was the result of a rigorous search for the most cost-effective solution available. Equipment from several manufacturers is now incorporated into what was originally an all-IBM system and each supplier normally provides or arranges for the maintenance of his own equipment. A review of these arrangements, which are both complicated and costly, was started in conjunction with the Central Computer Agency to determine whether they could be simplified and whether the overall cost, currently exceeding £300 000 per annum, could be reduced.

Some losses of specialist staff occurred but the effects were lessened by ensuring that staff in critical systems posts had a working knowledge of requirements outside their immediate areas of responsibility. Facilities for the internal training of programmers at the Meteorological Office College were expanded during the year, some specialist lecturers being provided by the Data Processing Branch.

The COSMOS computing installation

The COSMOS computing system is based on the powerful IBM 360/195 computer, coupled to the smaller IBM 370/158 computer. The latter releases the main processor for the more demanding work such as computing for numerical models of the atmosphere but, when the main 360/195 processor is unserviceable, the 370/158 has sufficient power to provide a back-up service for essential operational work. In normal operations the smaller processor provides line-drawing, plotting and remote-terminals services, undertakes the computation for most of the smaller tasks and handles all input and output requirements. The two processors share most of the 20 disc drives, the fixed-head disc and 10 of the magnetic-tape drives. The input and output devices are normally connected to the smaller processor, but may be switched to the 360/195 if the 370/158 fails.

The growth of time-critical operational work, such as line drawing and plotting, in recent years eventually led to a situation where, if the 370/158 failed, there was insufficient memory on the 360/195 to maintain these services while the main numerical forecasting model was being run. The installation of the second megabyte on the 360/195 fully restored the operational back-up capability in this respect and, in the short term, also provided some additional capacity to meet in part the needs of Research branches for increased computing for a wide range of numerical modelling work.

The continued expansion of the overall work-load also meant that the 370/158 became saturated early in the year and this was evidenced by a sharp increase in transfers of data and programs from virtual to real storage ('paging'). The addition of two megabytes of main memory, making four megabytes in all, drastically reduced this paging activity and provided some additional capacity to meet in part the needs of Services branches for increased computing for forecasting and climatological services, many of which produced useful revenue.

Three operating systems are required to operate the loosely coupled twin-processor system; the Asymmetric Multiprocessing System (ASP) to control the flow of work to and from the two processors, the Virtual Storage System (VS2) to control the work done in the 370/158 and the Multiprogramming System with a Variable Number of Tasks (MVT) to supervise the work done in the 360/195. Two new operating systems, Job Entry Sub-system 3 (JES 3) to replace ASP and Multiple Virtual Storage (MVS) to replace VS2, were developed ready for introduction early in 1979. JES 3 and MVS are better equipped to handle the increasing work-load over the next few years.

The COSMOS system continued to give generally reliable service. Availability of the 360/195 exceeded 98 per cent, except in August when 18 hours were lost owing to faults in the Power Distribution Unit, and in May and June when the Central Processing Unit (CPU) was withdrawn from service for 37 hours to install additional memory. Availability of the 370/158 also exceeded 98 per cent except in August when the CPU was withdrawn from service for 41 hours to install additional memory.

Support for computer-based applications

Most terminals are supported by Time Sharing Option (TSO) software. The number of user sessions taking place on these terminals remained at about 2800 per month and terminals were used extensively by three groups of staff: by programmers for the development and testing of new programs, by non-programming staff for the extraction of data to answer enquiries, and by staff in the Central Forecasting Office (CFO) and in the Telecommunication Branch for the monitoring and use of real-time data. The latter activities continued to expand and special support software was written to insulate such time-critical work from the effects of peak loads emanating from other terminals working under TSO. Terminal response was only slightly improved by the installation of extra memory on the 370/158, and a study of other methods of improving the response was commenced. Demand for terminal services remained strong and an improved version of a Job Control Language (JCL) syntax checker was introduced in May to assist program development from terminals.

An additional visual display unit (VDU) and printer were installed in CFO for operational work and a controller, two VDUs and two printers were installed at the Eastern Road site, one printer and one VDU being suitable for detachment to exhibition sites when required.

An IBM System 7 computer provides the interface between COSMOS and the automated telecommunication complex (AUTOCOM) and data are received in real time for processing in the synoptic data bank (SDB). The SDB suite of programs stores and controls the quality of real-time observational data in preparation for their use in analysis and forecasting programs and for their presentation to forecasters in various ways. The most time-critical operation is the automatic plotting of hourly charts of British Isles surface observations, particularly those for facsimile transmission to outstations. To meet this requirement the SDB suite of programs is designed so that data can be processed in an almost continuous stream from AUTOCOM for input to the chart-plotting programs.

Operational work based on real-time data continued to expand and the monitoring of data flow in Telecommunications, COSMOS and CFO remained an essential component of such work.

A NOVA 1200 computer, which controls 19 key stations in the PCK installation, was connected as a Remote Job Entry (RJE) system to COSMOS in November. Three other mini-computers: the PDP 11/40 in the Systems Development Branch, the PDP 11/36 in the Library and a PDP 11/10 at the Institute of Oceanographic Sciences, Bidston and been previously connected to COSMOS in this way.

The Calcomp microfilm and electromechanical plotters continued to play an important role in the graphical presentation of data to forecasters. During the year over 25 000 upper-air charts and over 40 000 charts of surface data were plotted, mostly for CFO, but many of these were also broadcast by facsimile to outstations.

The phased replacement of the two 1136 drum plotters, begun in 1977 with the installation of a 960 inclined flat-bed plotter, was taken a stage further with the installation of a second 960 plotter in April. The two 960 plotters, which are faster than the 1136 drum plotters, were used to prepare a wide range of plotted charts for operational use in CFO, master charts for facsimile transmission to outstations, and also master charts for reproduction by photolithography for the *Daily Weather Report.*

The two 1670 computer output on microfilm (COM) units were used primarily to produce the large-volume output of grid-point and line-drawn charts from each numerical forecast run, hard copies of which were produced by means of Xerox copiers in CFO. They were also used to produce some types of output in line-printer format on cine film.

Optimization

The systems team was heavily involved throughout the year in assessing and developing the new operating systems, JES 3 and MVS, and little effort could be assigned to further optimization of the existing operating systems. However, there was a steady expansion of work on programming techniques including the preparation and issue of further chapters of the Programming Techniques Guide. Assistance with the COSMOS-orientated programmer training at the Meteorological Office College, Shinfield Park and advice to branches on specific programming problems were also provided.

Continuing effort was required to produce management and accounting information to enable user branches to control their use of the computing time allocated to them and to provide information to the Directorate about the performance of the overall system and the changing demands made on it. By the end of 1978 the overall throughput of work had increased by about 25 per cent compared with 1977, and the number of jobs per month had increased from 30 000 in 1977 to about 36 000 in the last quarter of 1978.

Data management for the First GARP Global Experiment

The Meteorological Office agreed to operate a First GARP Global Experiment (FGGE) Area Sub-centre which is responsible for the management of synoptic data received over the Global Telecommunication System (GTS) from Africa, much of Europe and parts of the Middle East and for the subsequent collection of missing data from Africa. Although the operational year of the Experiment did not commence until December, it was preceded by a 12-month operational test phase in which vigorous efforts were made to collect missing

data by postal exchanges and to merge such data with those received via telecommunication channels. In spite of the very considerable difficulties of collecting data in this manner, postal collection of punched paper tape and magnetic tape from Africa increased the data coverage for countries which agreed to participate by 20 per cent, and overall by 10 per cent. The data were collected in sets covering 10-day periods and, when these were as complete as possible, they were sent to the FGGE surface-based Data Centre in Moscow and also to the FGGE space-based Data Centre in Sweden. Difficulties were initially experienced by these two centres in reading the magnetic tapes supplied by the UK centre and special precautions were taken to ensure that tapes produced in the later stages of the operational test were well within the standard specifications. Considerable international effort was needed to finalize the details of the world-wide data management plan for FGGE and the Office was represented at the relevant international meetings. A contract was arranged with British Airways to supply meteorological data recorded on magnetic tape during flights of Concorde and Boeing 747 aircraft during the operational year of FGGE.

Two 30-day special observing periods in 1979 were selected for the collection of data by special methods including the use of constant-level balloons, aircraft dropsondes, aircraft-based measurements and drifting buoys. The programs to handle new codes for these data (COLBA, TEMP DROP, CODAR and DRIBU) were completed and tested during the year.

Storage and preparation of data

The Redifon processor-controlled keying installation (PCK) and the punched-card unit are located in a specially designed data-preparation area. The PCK installation is equipped with 19 key stations, each having a visual display screen connected to a NOVA 1200 computer with line-printer, disc and magnetic-tape facilities. Keyed data, totalling about 25 million characters, were written to magnetic tape for transfer to the COSMOS data banks during 1978. A direct computer-to-computer link was installed in December to speed up the transfer of data between PCK and COSMOS, which was previously done by means of magnetic tape.

The card-punching staff handled about a quarter of a million cards for programmers in Headquarters—only half the 1977 figure—and the establishment was reduced. The remaining staff were trained to operate PCK data-entry stations and their co-location with PCK made it easier to maintain essential services during periods of PCK staff shortage.

Systems Development

Towards the end of 1977 the Systems Development Branch was given wider responsibilities and a new structure, based on a reorganization into three sections instead of two, came into being. All three sections are involved in the planning and implementation of new systems, usually based on or related to computers, but two of the sections also have substantial routine functions. The major routine task is the construction and support of the archival data base held on the Office's main computer system, COSMOS; a smaller one is the con-

version of data recorded on various media to magnetic tape which can then be handled by COSMOS.

Automation of outstation functions

Following the decision to introduce automated systems at certain major outstations, attention was directed first to the Principal Forecasting Office at London/Heathrow Airport. Detailed specifications were prepared for the equipment needed and discussions took place with potential suppliers towards the end of the year. It is expected that contracts will be placed early in 1979.

The use of small computers at major outstations will enable basic observations and forecast products from the operational numerical model to be transmitted from Bracknell at high speed, much of it in very condensed forms, and to be converted at the station in the order best suited to local priorities, using forms designed for ready assimilation by the forecasters. The system has been designed to provide for automation of chart plotting, drawing of contour charts, retrieval of data from the central COSMOS data banks and generation of specialized displays.

A similar system will be installed at the Principal Forecasting Office, HQ Strike Command in 1980. Studies were also started on a possible requirement for a similar system at the London Weather Centre and discussions took place with the Directorate of Naval Oceanography and Meteorology concerning a requirement for a compatible system at the Fleet Weather and Oceanographic Centre, Northwood.

Detailed consideration was given to the way in which automated centres will be linked to both the telecommunication (AUTOCOM) and data-processing (COSMOS) computer complexes at Bracknell. Arrangements were made to link the telecommunication system of the European Centre for Medium-range Weather Forecasts (ECMWF) to AUTOCOM, using a scheme based on the new international line protocol standard X-25. Preparations were made to link Heathrow to COSMOS initially by means of Remote Job Entry (RJE) facilities. However, an Operational Requirement was prepared for twin Telecommunication Processing Units which will gradually incorporate these functions into the AUTOCOM/COSMOS complex.

Computer processing of satellite imagery

The experimental processing of data from the US NOAA-5 polar-orbiting satellite continued throughout the year and a new task was the processing of data from the European geostationary satellite METEOSAT. Because of its orbit NOAA-5 only gave good coverage of the United Kingdom twice each day whereas METEOSAT, from its position over the equator on the Greenwich meridian, provided pictures every half hour although the view becomes inconveniently oblique in northern Britain.

As with NOAA-5, signals from METEOSAT were received at the Royal Aircraft Establishment station at Lasham and transmitted in analogue form over telephone lines to Bracknell where they were relayed to the PDP 11/40 computer which processed the image data. The signals were digitized and stored in readiness for further processing.

Image data from NOAA-5 were transformed on to a polar stereographic projection so that, following conversion back to an analogue form suitable for a facsimile recorder, a chart on a scale of 1:20 000 000 was produced which

was compatible with a number of working charts and was also convenient for nephanalysis (analysis of cloud types). Contrast and brightness of the images were adjusted to meet the needs of various users, for example to optimize the appearance of texture in clouds or to distinguish sea ice. Adjacent passes from NOAA-5 produced images which were merged to form a composite picture. One such composite, using the signal from the infra-red sensors on the satellite, was routinely archived each day using the microfilm plotter on COSMOS.

The format used for METEOSAT transmissions was such that direct reception on a facsimile recorder gave a very 'washed-out' appearance. The PDP 11/40 was used to convert the format and to modify the brightness and contrast so that better quality pictures were able to be provided routinely to the Central Forecasting Office.

Data from a small section of the METEOSAT infra-red pictures covering the southern part of the United Kingdom and the south-west approaches were transformed on to a transverse Mercator projection and transmitted in digital form to the Office's Radar Research Laboratory at Malvern for use in the Short Period Weather Forecasting Pilot Project. Data were transmitted both in a form compatible with the real-time signals from the weather-radar network and also in a more detailed form for later studies.

Two adjacent images from the visible wavelength sensor on METEOSAT were combined into one picture covering much of Europe between latitudes 35° and 70° N for use in connection with TV weather forecasts provided to the BBC (see Plate I). Several pictures were sent each day but the main use was in connection with the late forecast on Thursday evenings dealing with European weather.

Early in 1978 approval was given to obtain a computer system dedicated to the processing of satellite imagery on an operational basis and the procurement was well advanced by the end of the year. This new computer system will handle data from METEOSAT and from the new US polar-orbiting TIROS series.

Procurement of a new powerful scientific processor

It has long been recognized that the existing COSMOS configuration would gradually evolve as requirements for greater processing power were established. Three new requirements became well defined during 1978. It was agreed that the United Kingdom should play a significant role in the World Climate Program—a 20-year international program beginning in 1980. Meaningful experiments will require computing power an order of magnitude greater than that which can be provided by the IBM 360/195. Secondly, other experiments were designed to improve the accuracy of monthly forecasts by using the results of running numerical models as well as the statistical methods already used by the Synoptic Climatology Branch. The operational use of such a scheme would be well beyond the capabilities of the present system. Thirdly, additional computing power is required for the development of a mesoscale model suitable for forecasting detailed weather for 6–12 hours ahead. This model would meet certain Defence needs, as well as meeting public service requirements. A more powerful processor would also allow some areal extension of the numerical model used for 72-hour forecasts, for example to include the tropical regions between 20° N and 20° S.

Discussions took place within the Ministry of Defence, and with the Central Computer Agency and the Department of Industry, with a view to obtaining agreement for the Office to procure a powerful scientific processor. The Treasury gave general approval to the scheme in October and the Operational Requirement was issued in November for a powerful processor which will be added to COSMOS and will run in conjunction with the existing machines.

Computer-based data archives

There are two main sources of data that have to be archived and indexed: the continuing overflow of contemporary data and the backlog of records that need to be incorporated into the system. The archiving of contemporary data required less effort since schemes for their acquisition, quality control and organization into archive format became well established. In some areas branches such as Climatological Services assumed responsibility for routine quality control and entry of data of particular concern. Handling the backlog continued to give problems, particularly because of the poor quality of some of the earlier data.

Fairly long sequences of data are now available in the archives but there are some notable gaps, for example around the time when the present COSMOS system was introduced. The main emphasis during the year was therefore devoted to filling these gaps rather than extending the sequences back in time.

Evolving the best philosophy for quality control is a matter of considerable difficulty; some compromise has to be struck between filling all possible entries in the data base and avoiding the presence of any erroneous data. Given sufficient effort almost any desired standard can be achieved but the results may not be cost-effective. Computer programs can assist, especially in the detection of errors, but it is often difficult to develop algorithms which can make corrections, even those which would be immediately obvious to the meteorologist.

The archive is held on magnetic tape and, even using a packing density of 6250 bits per inch, poses storage and handling problems. Accordingly a review was made of mass storage systems that would both reduce the number of physical volumes (i.e. individual racks of tape, film etc.) to be handled and offer a medium with better archival qualities than magnetic tape. One of the more interesting developments was one which uses holographic techniques on either photochromic film, which is re-usable and does not require processing, or on orthodox silver film.

Optical character recognition has made substantial progress in recent years and a study of its applicability to the acquisition of some contemporary data was started.

Systems studies

Experiments aboard aircraft of the Meteorological Research Flight (MRF), based at the Royal Aircraft Establishment (RAE), Farnborough, produce enormous quantities of data which have to be analysed with the aid of computers. Because of the difficulty of using the Bracknell computers from MRF and a sharp reduction in the amount of computer time that RAE were able to provide, it became clear that MRF needed its own new and comprehensive computing facility. The Systems Development Branch assisted in drafting an Operational Requirement and in other steps in the procurement exercise.

Now that courses for programmers are included in the regular training

program of the Meteorological Office College, the need for effective access to COSMOS from Shinfield Park has been recognized. The Branch prepared a study paper which considered the merits of various means of connection to COSMOS and helped to prepare a case. It was decided to proceed with a small computer system which would give Remote Job Entry facilities but which could be enhanced later to provide a local computing capability and to offer, for training purposes, some of the facilities to be provided at automated outstations. The Branch prepared an Operational Requirement and became involved in the procurement negotiations with the Central Computer Agency on behalf of the College.

A preliminary study was carried out for the Personnel Management Branch into the possibility of using computer methods to assist in the handling of personnel records and to set up models to assist in manpower planning. The results suggested that a more detailed study should be undertaken and this was initiated towards the end of the year.

An experiment to provide data for the Post Office's Prestel data base (see page 21) direct from COSMOS (without manual intervention) via the PDP 11/40 was arranged for the Public Services Branch, and was still in progress at the end of the year. Steps were taken to enhance the Meteorological Office Library's small computer system so that the whole catalogue from October 1971 to the present can be made available on-line. Tenders for the necessary equipment were received by the end of the year.

The PDP 11/40 computer fulfilled two main roles; firstly as a test bed to develop new techniques and secondly as a facility for routine data conversion. The most demanding experiment is the processing of satellite image data, described earlier. A substantial amount of time was devoted to the development of programs in CORAL language for the computer system to be installed at Heathrow, mentioned under 'Automation of outstation functions'. Other experiments in progress during 1978 were interrogation of automatic weather stations, development of programs for the computer system in the Library, and the testing for the High Atmosphere Branch of terminal equipment at the United Kingdom end of the trans-Atlantic link installed to receive data from the Stratospheric Sounding Unit aboard TIROS-N. In addition computer time and expertise to a value of about £4500 were sold to an outside customer for use in connection with an experiment to digitize and partially analyse seismic data. Because of the increasing load of data conversion work, particularly from magnetic-tape cartridges to standard half-inch computer tape, the PDP 11/40 configuration was enhanced by the addition of a second subsystem for cartridges, a second tape deck for 1600 bits/inch magnetic tape and 16 kilowords (16-bit word length) of main memory. The High Atmosphere Branch made considerable use of the D-Mac pencil-follower to convert upper-air analyses into digital format. The handling of paper tape from the pencil-follower became inconvenient so an electronic link to the PDP 11/40 was implemented in conjunction with the High Atmosphere and Operational Instrumentation branches.

Meteorological Telecommunications

The Telecommunication Branch is responsible for the provision of general communication support to the whole of the Meteorological Office, for the operation of the main Meteorological Office Telecommunication Centre (Met

TC) located at Bracknell, and for the organization of the complex network of lines through which information vital to the provision of meteorological services is collected and distributed. Meteorological observations of many kinds have to be collected and exchanged; analyses, forecasts and information derived from meteorological satellite observations have to be disseminated. These information transfers must be effected speedily and with a high degree of reliability. The involvement of computer systems in the handling of information continues to increase, and to operate efficiently these systems require that both format and content of data transmissions are accurate. Detailed control procedures and careful monitoring of the operations ensure the high integrity of messages transferred through the Bracknell Centre.

As a Regional Telecommunication Hub (RTH) on the Main Trunk Circuit (MTC) of the WMO Global Telecommunication System (GTS), Bracknell has responsibility for the link between Europe and North America, and for the dissemination of traffic to a number of National Meteorological Centres (NMCs) in northern Europe. The MTC connections are to the Paris RTH and to the World Meteorological Centre (WMC) in Washington. These circuits operate automatically, transmissions of digital data at 2400 bits/second alternating with transmissions of pictorial information in analogue mode. A Main Regional Circuit between Bracknell and Offenbach in the Federal Republic of Germany operates in a similar fashion. The regional circuits to the other NMCs (except Reykjavik in Iceland) operate in digital mode only and, where required, transmissions of pictorial information are made over separate facsimile networks. A further responsibility of the Bracknell RTH is the collection of observational data from Greenland, Iceland, Gibraltar, the Netherlands, the Republic of Ireland, and from the weather ships of the North Atlantic Ocean Station (NAOS) network. Together with messages compiled at Bracknell from data collected from the United Kingdom, these reports are transmitted on the MTC and are thus available for distribution throughout the GTS as required.

The Met TC forms the central hub of an extensive network of teleprinter and facsimile circuits by means of which Bracknell is able to fulfil its role as the NMC for the United Kingdom. Observational data and processed information are collected and distributed and, in addition, pictorial information from meteorological satellites is received over a direct connection from the satellite ground station at Lasham and distributed over a dedicated facsimile network (SATFAX). The expansion of these services to provide for the receipt of information from the new METEOSAT and TIROS-N satellite systems has been an important aspect of the work of the Branch during the year. The Centre also provides information for meteorological radio broadcasts designed to provide reception over a range of about 3000 km from UK to various recipients including ships at sea and other national meteorological services. Two radio-facsimile broadcasts and a radio-teleprinter broadcast provide for the transmission of both pictorial and alphanumeric information. Facilities exist for the reception of similar radio broadcasts from neighbouring RTHs, so that some limited exchange of data can continue if there are major failures of the land-line networks. The Met TC is operated in accordance with agreed international and national procedures for the collection and distribution of meteorological information on global, regional and national scales. Members of the Branch play an active role on the international working groups which study requirements and formulate procedures for ensuring the compatibility of neighbouring

systems and facilitating efficient data exchanges. Many of the functions of the Centre are now automated and require skilled support from the telecommunication staff, engineers and meteorologists, who together constitute the staff of the Telecommunication Branch.

Items during 1978 worthy of special mention were the growth in the services provided by the Bracknell Automated Telecommunication Complex (AUTOCOM); the new remote-controlled radio receiving equipment for the NAOS Shore Station which was brought into operation early in the year, together with a microprocessor-controlled data-entry system which enables the NAOS radio operator to feed messages directly into the automated system (see Plate IV); the major revisions to the schedules of products transmitted on all the facsimile networks; and the important development work which was undertaken to provide a medium-speed data link to the European Centre for Medium-range Forecasts (ECMWF).

Bracknell Automated Telecommunication Complex

The twin Marconi Myriad II message-switching computers, on which all operations in the automated complex (AUTOCOM) are based, control the operation of the MTC circuits to Paris and Washington (at 2400 bits/second); the regional circuits to Offenbach (2400 bits/second); Oslo, De Bilt and Dublin (1200 bits/second); and many low speed (50 bits/second) teleprinter circuits including links to Brussels, Rheindahlen, Hilversum, Reykjavik, Gibraltar, Cyprus, Malta, and to 11 data-collection centres and many outstations in the United Kingdom. An IBM System 7 computer is used to control the transfer of data between AUTOCOM and the main data-processing computer system (COSMOS). The 1200 bits/second link to the new automated message switching system in Dublin is not yet fully operational, although good progress has been made with tests conducted in the latter half of the year. Routine information sent from Bracknell to Dublin was successfully received and distributed by the Dublin system. Transmissions in the reverse direction will begin early in 1979.

Increased traffic through AUTOCOM arose from two major international projects; 1978 was the build-up year during which special efforts were made to improve the availability of data and to test reporting procedures to be used during the First GARP Global Experiment (FGGE) which runs from December 1978 to November 1979 with the first special observing period planned for January 1979. Also the European Space Operations Centre (ESOC) at Darmstadt commenced operational service following the launch of the METEOSAT satellite and, to support these operations, ESOC required a large number of GRID-code messages containing analyses and forecasts originated by WMC Washington, which were relayed over the MTC. These additional demands required significant changes to be made to the AUTOCOM control program. Following studies undertaken by external software consultants, changes were made in April which increased the capacity of the system Routeing List by a factor of nearly two. Further modifications to the system were planned to ensure that an effective service can be maintained during the FGGE period. These modifications became necessary because of serious delays in the delivery of the Ferranti Argus 700S computer system which will eventually become the Main Enhancement to the present system and which had been intended to carry the additional traffic expected in the FGGE period and subsequently. Through-

out the year this project continued to make slow and disappointing progress and the contract, originally scheduled (when it was placed late in 1974) to take two years, has now dragged on for four. It is apparent that the new equipment, far from assisting in a major way throughout the whole of the FGGE build-up and operational years, will not now be operational until at least the summer of 1979 with only a few months of the FGGE still to run.

Facsimile schedules and developments

A major task undertaken early in 1978 was the revision of the transmission schedules for all the facsimile services provided from the Met TC. The introduction of changed times of issue of North Atlantic (NAT) analyses and aviation forecasts from the numerical forecast suite made the revisions necessary and led to the provision of a more timely service for the distribution of these products. Advantage was taken of this opportunity to rationalize the operational procedures within the facsimile section of the Met TC. The new schedules for the BRAMFAX and BRITFAX radio-facsimile broadcasts, and for the MOLFAX, PANFAX and Aviation Forecast System (AFS) land-line networks were introduced in March. Because of the interrelationship of these services, particularly the last named, with those provided by a number of other meteorological centres in Europe, these changes involved consequential changes to the transmissions from these centres also and minor modifications to the new schedules were not finally completed until several months later.

Although progress with the development of digital facsimile during the year was slow owing to the diversion of effort to other projects, nevertheless some useful work was done using the Ferranti Argus 700E mini-computer obtained for this purpose. Further tests of coded digital facsimile transmissions on the MTC are planned for early in 1979.

Satellite data reception and distribution

The RAE satellite ground station at Lasham provided cloud images on a routine operational basis throughout the year. Very High Resolution Radiometer (VHRR) images from the United States NOAA-5 polar orbiting satellite were received throughout the year, and Vertical Temperature Profile Radiometer (VTPR) data from the same satellite were made available as required for use in the Research branches. Images from the Scanning Radiometer (SR) system were also received until it failed in February.

Sectorized images of the British Isles and the surrounding area as well as the SR images until February, were made available to the outstation network. When the SR system failed, a variant of the equipment used for producing VHRR sectors was quickly developed to produce an output derived from the VHRR data which closely resembled the original SR products.

During the year much effort was devoted to the improvement of the images received from the METEOSAT satellite of the European Space Agency. Throughout the period the quality of transmissions from this geostationary meteorological satellite was very variable and equipment had to be developed and installed at the Lasham receiving station to permit some adjustment of the images, before onward transmission to Bracknell, in order to extract a greater amount of information.

TIROS-N, the first of the new series of United States polar orbiting meteorological satellites, was launched on 13 October and reception of its SR images commenced at the Lasham site on 16 October when the visual spectrum radiometer was switched on. SR pictures from the satellite were being supplied to the Central Forecasting Office on a routine basis by the end of the year. During the summer a special trans-Atlantic link was established between Bracknell and the US National Environmental Satellite Service at Suitland, Maryland. The link, which operates at 2400 bits/second, was used for the supply of data from the Stratospheric Sounding Unit (SSU) on TIROS-N to the High Atmosphere Branch for monitoring and evaluation. The terminal at the UK end of the link was installed in the Met TC, and recordings were supplied routinely to the High Atmosphere Branch.

Because the recording equipment used at the 20 offices on the SATFAX network was only compatible with transmissions from the NOAA series of US satellites, further equipment was developed and brought into use at Lasham and a start was made with modifying the receivers themselves to provide for reception of transmissions from both METEOSAT and the TIROS-N series of satellites. By the end of the year this program was well advanced and the distribution of METEOSAT images to outstations on a routine basis had begun.

Owing to the failure of the SR services from the NOAA-5 satellite in February, the overseas receiving stations at Gibraltar, Malta, Cyprus and Rheindahlen, were deprived of satellite imagery for a large part of the year. With the successful launch of TIROS-N, arrangements were made to provide suitably modified reception and display equipment at Gibraltar, Cyprus and Rheindahlen, there no longer being a responsibility to support the equipment at Malta.

Automatic Message Preparation Equipment

The first production model of Automatic Message Preparation Equipment (AUTOPREP) is due to be delivered to Bracknell early in 1979 and the rest of the production run at intervals during the year. AUTOPREP terminals comprise a visual display unit and key-board, supported by storage and format-generating facilities, and will be installed at a number of important meteorological offices in the United Kingdom as well as at the Bracknell Met TC. The terminal will provide facilities for the compilation of meteorological bulletins, and also messages and forecasts of various kinds for transmission to consumers such as the BBC, public utilities and the Press; direct connection to the Post Office telex system will be incorporated in some cases.

Telecommunication network protocol developments

In recent years there has been world-wide interest in the adoption of new protocols for the control of digital data transmissions over communication lines. Following the adoption by the International Telegraph and Telephone Consultative Committee (CCITT) of a standard for a new protocol which was developed in close association with the International Standards Organization (ISO), Recommendation X-25 was published. This provides standards for data transmissions and for the control of lines and access of terminals to packet switched networks. These proposals have been adopted by the Conférence Européenne des Postes et Télécommunications (CEPT) as the standards to be used for public data networks in Europe. Since such developments are of great

concern for future meteorological communication systems these proposals were carefully studied by technical staff in the Office. A decision was reached that a system based on the X-25 recommendations should be used to control transmissions of information on the medium-speed data link to be established between AUTOCOM and the European Centre for Medium-range Weather Forecasts (ECMWF). The Ferranti Argus 700E computer used for development work within the Branch was equipped with the necessary ancillary equipment and much effort was expended to develop software to support the new line protocol system. The new protocols will later be used over other medium-speed links to the automated systems to be established at major outstations such as London/Heathrow Airport.

International and Planning

International co-operation is vital for both the day-to-day operation and the development of meteorological services, and the Meteorological Office has continued to play an important role through a number of international organizations. Foremost in meteorology is the World Meteorological Organization (WMO), an intergovernmental organization in which the Permanent Representatives of Member States are normally the Directors or Heads of their Meteorological Services. It is through WMO that almost all international co-operation in meteorology is conducted, procedures and standards are agreed, and networks of observing stations and telecommunications are planned and co-ordinated. In addition to its Congress and Executive Committee which meet in Geneva, the WMO has six Regional Associations which meet to discuss and deal with meteorological and hydrological problems on the continental rather than the global scale; the United Kingdom belongs to Regional Association VI (Europe) and also, because of continuing commitments to its few remaining island dependencies, to Regional Association I (Africa). The United Kingdom is also represented on each of the eight Technical Commissions which deal with separate but world-wide aspects of the science of meteorology and its applications.

The addition of operational hydrology to the responsibilities of WMO has required some new working relationships, since work in the United Kingdom on operational hydrology is done largely by bodies other than the Meteorological Office. An inter-departmental committee for hydrology looks after co-ordination of international matters, and its Chairman, the Director of the Central Water Planning Unit, is also Hydrological Adviser to the Director-General of the Meteorological Office as UK Permanent Representative with WMO.

The world-wide basic systems for observation, collection, dissemination, storage and retrieval of meteorological data comprise the World Weather Watch (WWW) program of WMO. The United Kingdom has added to the global network over the last ten years by the establishment of a number of stations making surface and upper-air observations, and continued to support them.

St Helena is operational and still awaits the completion of the telecommunication link in Kano, Nigeria to become a fully functional part of the Global Observing System of the WWW. In the meantime data have been transmitted through other, circuitous routes. This station, set on a small island in the South Atlantic Ocean, is manned by officers from the United Kingdom who do a tour of 18 months duty; the observing staff is recruited and trained

locally. Access to the island presents a difficulty as there is no airport. However, the joint venture between the Government of St Helena and a private shipping company is now in full operation and the island can be reached from South Africa on an 8-week schedule. During the year, the Diplomatic Wireless Service staff on the island were withdrawn and the Meteorological Office took over the equipment required for the transmission of meteorological messages.

The United Kingdom continued to second two officers to the WWW station at Mahé which is now operated by the Seychelles Meteorological Department; the training of a Seychelles technician commenced in the United Kingdom. A Gilbertese was sent for a long course of training in New Zealand with a view to his filling the Technical Officer post at the upper-air station on Tarawa (Gilbert Islands).

The observer post at the Royal Society Research Station on the atoll of Aldabra continued to be filled by volunteers from the Meteorological Office. Most of these posts are in isolated spots and some particular qualities such as resourcefulness and determination are called for; volunteers continued to come forward.

The WMO Agreement on North Atlantic Ocean Stations (NAOS) continued in operation, maintaining the network of weather ships which makes surface and upper-air observations in the Atlantic that are of value to much of North America and Europe. Although states continued to join the NAOS scheme its future after 1981 remains in doubt and the NAOS Board agreed to fund a study of possible alternative observing systems to the fixed ocean stations.

The WMO Voluntary Assistance Program (VAP) was established so that less-developed countries might be helped in carrying out their responsibilities under WWW. The Office continued to give its support. During 1978 the radar wind-finding station at Kasama in Zambia was completed and a further wind-finding radar is being installed at Mongu in the same country. Two other wind-finding radars were delivered to Mauritius for use on the islands of Rodrigues and St Brandon. Radiosonde consumables were despatched to Mauritius, Sudan, The Niger, Senegal and Guinea for use during the WMO Global Weather Experiment and offers of similar support were made to Mauritania. Arrangements for short-term fellowships for training staff from developing countries, particularly in the installation and operational equipment provided under VAP, continued.

Mr Palamoudian, the WMO Telecommunication Expert for Africa, visited the Office in March for discussions about VAP projects in Africa. Mr Zavos, Chief of the VAP Branch of the United States National Oceanic and Atmospheric Administration (NOAA) visited the Office in July to discuss co-operation in VAP projects and see the training of three NOAA technicians on UK manufactured wind-finding radars. It is intended that the NOAA technicians will assist in the servicing of wind-finding radars provided by the United Kingdom under VAP schemes in countries which they visit when supporting United States' VAP projects.

The selection of VAP projects for implementation by the United Kingdom has been primarily on scientific and technical grounds, in keeping with the traditional role of meteorologists and in line with priorities set by WMO. The Assistant Director (International and Planning) represented the United Kingdom at a meeting in June of the Executive Committee Panel on VAP. The Panel reviews policy and guidelines for the implementation of VAP (Equipment

Services) and controls the use of the VAP Fund, to which the United Kingdom is a contributor. Within the Office there is a continuing reappraisal of policy and a questioning of the assumptions on which that policy is based, with the intention of ensuring that money spent on supplying equipment and services is used to the best advantage. To this end, and to provide information to support the preparation of a 5-year program of technical co-operation projects, an Officer of the International and Planning Branch spent three weeks in November in Africa investigating local conditions in selected countries.

Preparation for the Global Weather Experiment, as the First GARP Global Experiment is now known, continued throughout the year. Arrangements for the making and collection of special observations and the dissemination and handling of data were tested and necessary improvements made.

The meteorological aspects of other international activities are dealt with through such organizations as the International Civil Aviation Organization (ICAO) and the North Atlantic Treaty Organization (NATO). The International Council of Scientific Unions (ICSU), in which scientists participate as individuals rather than as representatives of scientific bodies, is responsible, together with WMO, for the Global Atmospheric Research Program.

The European Centre for Medium-range Weather Forecasts (ECMWF) works in co-operation with WMO. It is staffed by scientists drawn from the European countries contributing to ECMWF and about 40 per cent of the senior posts are occupied by UK staff.

The permanent buildings for the Centre, at Shinfield Park, Reading, donated by the United Kingdom, were almost completed during 1978 and the staff of the Centre moved into their office accommodation during October. The powerful computing facilities approved by the Council for the ECMWF during 1977 were installed late in the year.

Mr G. J. Day, Assistant Director (International and Planning) was elected Chairman of the WMO Executive Committee Working Group on Antarctic Meteorology. The Meteorological Office continued to give assistance to the British Antarctic Survey (BAS) in the funding of WWW stations in the Antarctic. Particular attention was given to securing the continued operation of the WWW station at Halley Bay during the Global Weather Experiment by the provision of radiosonde consumables and the purchase of a hydrogen generator.

The Program Review Committee (PRC) of which the Directors, Deputy Directors and the Secretary of the Meteorological Office are members, met under the Chairmanship of the Director-General twice during the year. The PRC reviews the progress of the activities of the Office and decides on the direction and distribution of effort each year and for up to 10 years ahead. The Assistant Director (International and Planning) is Secretary to the PRC.

F. H. BUSHBY
Director of Services

STATISTICS OF THE SERVICES DIRECTORATE

The quantitative analyses in this section are intended to provide an indication of the distribution of work within the Directorate of Services and of the extent of the services provided.

TABLE I—NUMBERS OF OFFICES OF VARIOUS TYPES STAFFED BY THE METEOROLOGICAL OFFICE AND OPERATING ON 31 DECEMBER 1978

	Within UK	Overseas
Principal Forecasting Offices associated with the RAF	1	—
Main Meteorological Offices associated with the RAF	6	3
Subsidiary offices associated with the RAF	27	5
Observing offices associated with the RAF	6	1
Principal Forecasting Offices associated with civil aviation ...	1	—
Main Meteorological Offices associated with civil aviation ...	3	—
Subsidiary offices associated with civil aviation	10	—
Observing offices associated with civil aviation	8	—
Upper-air observing offices	8	2
Public service offices	6	—
CRDF offices	5	1
Port Meteorological Offices	6	—
Offices associated with the Agricultural Development and Advisory Service (MAFF)	4	—
Other offices	22*	2

*Four of these stations are administered by DR Met O.

Notes

A Principal Forecasting Office meets the needs of aircraft flying over long distances and operates through the 24 hours.

A Main Meteorological Office operates through the 24 hours for the benefit of aviation and normally supervises the work of subsidiary offices.

A subsidiary office is open for that part of the day necessary to meet aviation requirements.

At an observing office no forecaster is available.

An upper-air observing office may be located with an office of another type if this is convenient.

Public service offices are located in certain large cities.

CRDF offices form the network for thunderstorm location.

Port Meteorological Offices are maintained at the bigger ports.

TABLE II—OCEAN WEATHER SHIPS

To meet the United Kingdom obligations under the WMO Agreement for the Joint Financing of the North Atlantic Ocean Stations (NAOS), the Office operated two ocean weather ships. These were employed to man ocean station 'L' (57°00'N, 20°00'W), one of the four stations of the network, each ship spending an average of 24 days on station each voyage. The station was manned for a total of 351·7 days in 1978 and the two ships were on passage for 76·3 days. Two ships from France, one from the Netherlands, one jointly operated by Norway and Sweden and five ships from the USSR served at the other three stations.

TABLE III—MERCHANT NAVY SHIPS

A total of about 7035 ships of the merchant navies of the world make and transmit meteorological reports to the appropriate meteorological centres ashore under arrangements co-ordinated by the World Meteorological Organization. Most of them, including British ships, do this on a voluntary basis. Ships which report in full at four specified times daily are known as 'selected ships'; those which report at the same times daily, but in a less complete form, are known as 'supplementary ships'. A number of coasting vessels, lightships, distant-water trawlers and 'auxiliary ships' also make and transmit meteorological observations.

On 31 December 1978 the numbers of British ships reporting were:

Selected ships	489
Supplementary ships (including 5 trawlers)	30
Coasting vessels	56
Lightships (including 1 light-tower)	14
Trawlers	1
Auxiliary ships	6
Total	596

The British Voluntary Observing Fleet includes ships of many shipping companies, and the numbers on the various routes are as follows:

UK to Australasia	37
UK to Far East	40
UK to Persian Gulf	31
UK to South Africa	33
UK to West Indies	21
UK to Atlantic coast of North America	60
UK to Pacific coast of North America	9
UK to South America	13
UK to European ports	67
UK to Falkland Island and Antarctica	2
UK to distant-water fishing grounds	10
World-wide tramping	188

During two typical five-day periods, one in June, the other in November, the average daily numbers of reports from ships received at Bracknell were as follows:

	Reports *June*	Reports *November*
Direct reception from:		
British ships in eastern North Atlantic	137	119
Foreign ships in eastern North Atlantic	90	88
British ships in North Sea	23	25
Foreign ships in North Sea	16	4
Ships in other waters	12	21
Total	278	257
Reception via other countries:*		
Ships in eastern North Atlantic	582	501
Ships in western North Atlantic	327	233
Ships in Mediterranean	60	37
Ships in North Sea	89	89
Ships in Arctic Ocean	74	63
Ships in North Pacific	633	749
Ships in other waters	272	287
Total	2037	1959

*Via the Global Telecommunication System.

TABLE IV—CLASSIFICATION OF STATIONS SUPPLYING CLIMATOLOGICAL INFORMATION

For climatological purposes, data are obtained not only from official sources but also from very many stations which are not part of the Meteorological Office. The following table shows the distribution on 31 December 1978 of stations which supply climatological information. The areas and titles of the districts are those used in the *Monthly Weather Report*.

	Stations Supplying Returns							Stations Supplying Autographic Records		
	Observatories	*Met. O. Synoptic*	*Auxiliary Synoptic*	*Agrometeorological*	*Climatological*	*Holiday Resorts*	*Rainfall**	*Sunshine*	*Rainfall*	*Wind*
Scotland, north	1	6	5	2	30	0	310	25	7	15
Scotland, east	0	6	5	7	55	2	555	40	9	12
Scotland, west	1	5	8	2	47	0	506	26	10	16
England, east and north-east ...	0	7	4	8	20	5	498	29	18	14
East Anglia	0	11	1	13	20	3	461	28	11	15
Midland Counties	0	7	3	13	38	0	1236	47	20	15
England, south-east and central southern	1	11	4	17	30	16	774	53	31	20
England, south-west	0	7	12	5	29	9	639	29	8	13
England, north-west	0	5	1	3	16	2	516	16	21	11
Isle of Man	0	1	1	0	0	1	21	3	1	2
Wales, North	0	1	3	3	14	3	274	9	2	13
Wales, South	0	3	5	7	15	2	350	15	6	7
Channel Islands	0	2	0	0	1	2	20	6	0	1
Northern Ireland	0	1	7	7	48	0	273	30	50	11
Total	3	73	59	87	363	45	6429	356	194	165

*Includes stations in earlier columns.

TABLE V—HEIGHTS REACHED IN UPPER-AIR ASCENTS

The following table shows the number of upper-air ascents giving observations of (a) temperature, pressure and humidity, and (b) wind, which have reached specified heights, and the height performance of the largest balloons.

	Number of observations	Percentage of all balloons reaching 100 mb (≈ 16 km)	50 mb (≈ 20 km)	30 mb (≈ 24 km)	10 mb (≈ 30 km)	Percentage of largest balloons reaching 10 mb (≈ 30 km)
(a) *Temperature, pressure and humidity:*						
Eight stations in the UK ...	5757	92·8	81·4	61·8	19·2	51·6
Two stations overseas	1458	95·7	89·0	77·1	42·4	57·2
One Ocean Weather Station (two ships)	845	94·0	79·4	61·5	6·4	—
(b) *Wind:*						
Eight stations in the UK ...	11 629	89·9	68·4	38·2	10·1	53·4
Two stations overseas	2911	94·1	79·2	51·4	24·4	65·0
One Ocean Weather Station (two ships)	1374	88·1	67·7	44·4	3·3	—

TABLE VI—THUNDERSTORM LOCATION

Number of thunderstorm positions reported by CRDF Network:
In 1978 ... ... 49 504

TABLE VII—METEOROLOGICAL COMMUNICATION TRAFFIC

Almost all the national and international exchanges of meteorological data which are used in the construction of synoptic charts and the production of forecasts are effected by coded messages. The coded messages comprise mainly groups of five figures, and there may be from 5 to around 300 such groups in one message. The messages are exchanged by radio and land-line facilities. In addition there is an exchange, both nationally and internationally, of meteorological information in pictorial format. This information is largely analyses and forecasts derived from processing observational data. The transmission method is analogue facsimile by either radio or land-line.

The following figures give an analysis of the traffic (mainly coded messages and information in pictorial format) through the Meteorological Office Telecommunication Centre, Bracknell, for one typical day (24 hours) taken in November 1978 and, for comparison, some corresponding figures are given for one day near the end of 1977.

	In	Out	Total	Total in 1977
Coded messages:		*number of groups in one day*		
Land-line teleprinter and data transmission	677 255	2 913 438	3 590 693	3 122 484
Radio transmission	12 125	179 145	191 270	199 394
Facsimile charts (pictorial format):				
		number of charts in one day		
Land-line transmission ...	240	968	1208	1094
Radio transmission	100	115	215	209

Closure of the link to Malta in October has resulted in a small decrease in transmission of messages by radio, but in general the services provided by the Met TC continue to increase, and the total number of groups handled (in and out) shows a considerable increase over the previous year.

TABLE VIII—SPECIAL SEASONAL FORECASTS

There is a need for forecasts of a special type at certain seasons. These are described in *Met O Leaflet No. 1.* The numbers receiving such specialized services are as follows:

	Year	Number of customers	Year	Number of customers
Dry-spell notifications (a summer service primarily for farmers	1977	137	1978	133
Week-end temperature forecasts (a winter service primarily for industrialists) ...	1977/78	68	1978/79	85
Winter road-danger warnings (primarily for local authorities)	1977/78	285	1978/79	303

TABLE IX—FORECASTS FOR AVIATION

Forecasting for aviation constitutes the primary function of many of the offices. The Central Forecasting Office, acting as a Regional Meteorological Centre of the World Weather Watch, is mainly concerned with the analysis of the weather situation and with the issue of forecast charts for the guidance of other offices, including the two Principal Forecasting Offices which serve civil aviation from London/Heathrow Airport and military aviation from the Headquarters of RAF Strike Command. The Central Forecasting Office also has a commitment to civil aviation in the provision of wind and temperature charts for use with the significant weather charts produced by the Principal Forecasting Office at Heathrow and for the transmission of grid-point data direct to the British Airways BOADICEA and APOLLO computers at Heathrow and Prestwick respectively and to the Dutch and Belgian Meteorological Services.

The following figures indicate the numbers of forecasts issued for aviation and the numbers of meteorological briefings that took place during 1977 and 1978. These do not include warnings and routine general forecasts.

	1977	1978
Number of meteorological briefings for		
aviation in the UK	356 818	367 932
aviation at overseas stations	41 473	35 948
Number of aviation forecasts issued for		
aviation in the UK	1 916 359	2 074 070
aviation at overseas stations	259 755	220 824

TABLE X—NON-AVIATION ENQUIRIES

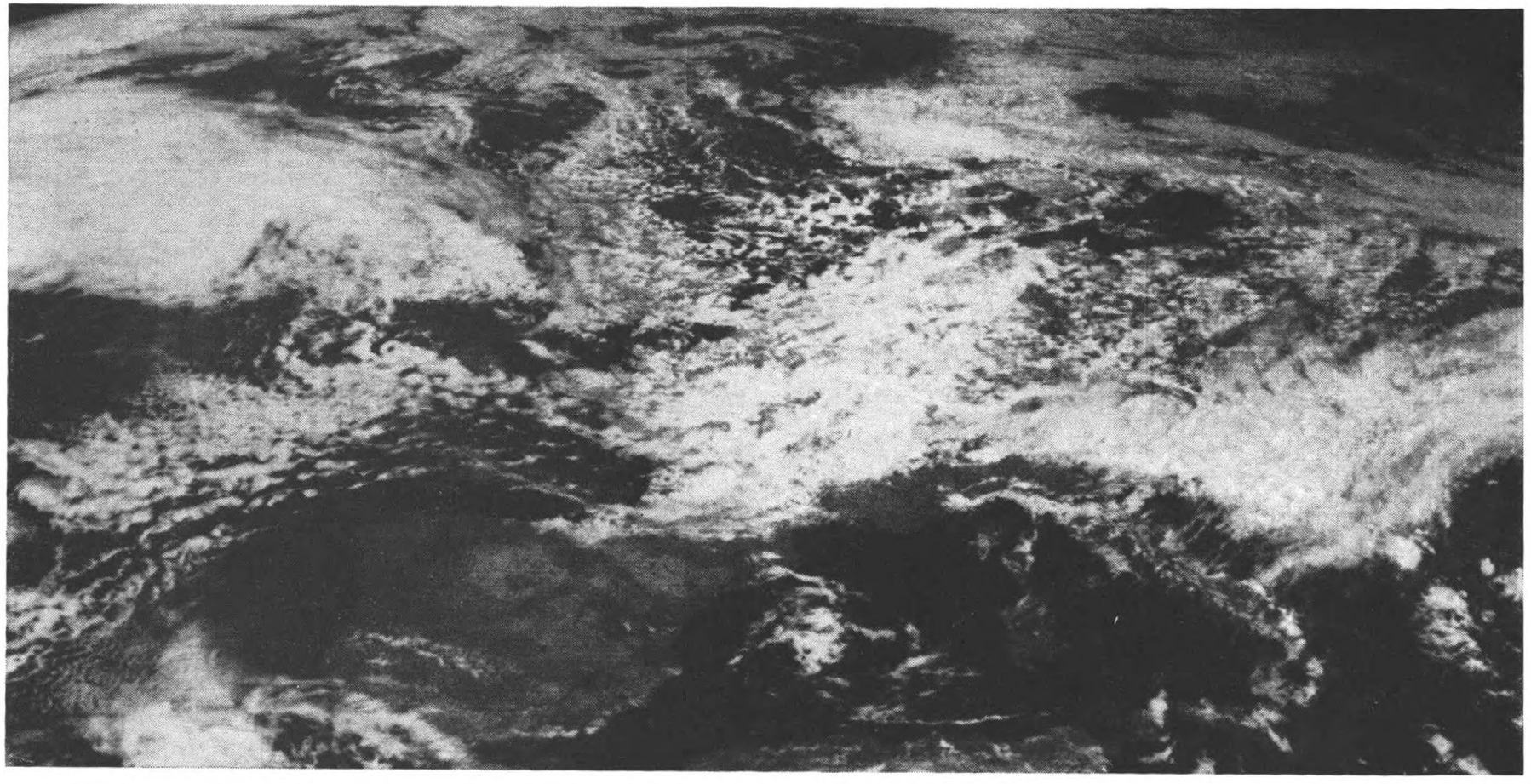
Non-aviation enquiries are handled by six Weather Centres, in London, Manchester, Glasgow, Southampton, Newcastle and Nottingham whose function is to meet the needs of the general public for forecasts for special purposes. Many other forecast offices, established primarily to meet the needs of aviation, also answer requests for forecasts and other weather information from the general public, Press, public corporations, commercial firms, etc. These inquiries, most of which refer to current or future weather, are listed below according to the purpose of the enquiry.

	1977	1978
Total number of non-aviation enquiries	1 973 002	2 107 778
Percentage relating to:		
agriculture	13·1	14·1
building	4·7	4·3
commerce, industry	4·8	4·3
holidays	19·1	19·0
marine matters	14·6	13·3
Press	10·0	9·3
public utilities	8·7	8·5
road transport	7·2	10·2
other known purposes	6·7	5·9
unknown purposes	11·1	11·1

TABLE XI—FLASH WEATHER MESSAGES

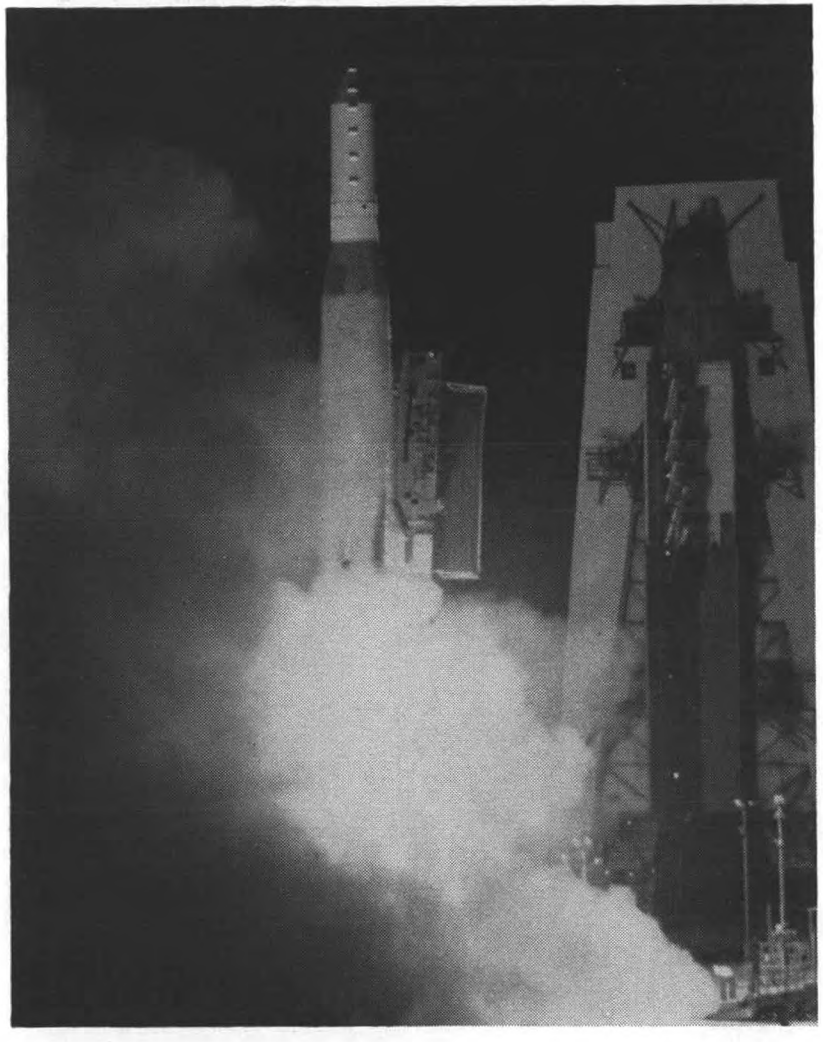
FLASH weather messages are passed to the BBC and to most independent broadcasting companies for inclusion in their programs at a convenient break. They are, effectively, warnings of the actual occurrence of weather conditions which might cause considerable inconvenience to a large number of people. The following table shows the kind of weather and areas of the country for which FLASH messages are broadcast and the number issued in 1978.

Area	Dense fog	Moderate or heavy snow	Heavy rain	Glazed frost and icy roads	Severe inland gales
Edinburgh and south-east Scotland	—	5	2	—	2
Glasgow and south-west Scotland	—	4	4	1	6
Belfast and Northern Ireland	—	2	3	—	5
Industrial north-east England	—	6	2	1	3
Industrial Lancashire and Merseyside	3	1	3	1	3
Industrial Midlands	2	3	1	—	—
Bristol and Bath	—	1	—	—	1
South Wales	—	3	6	2	5
London and south-east England	2	1	3	2	1
Plymouth and south-west England	—	3	2	—	3
Yorkshire	3	—	1	—	2
Southampton and Portsmouth	—	—	2	—	—
Totals	10	29	29	7	31



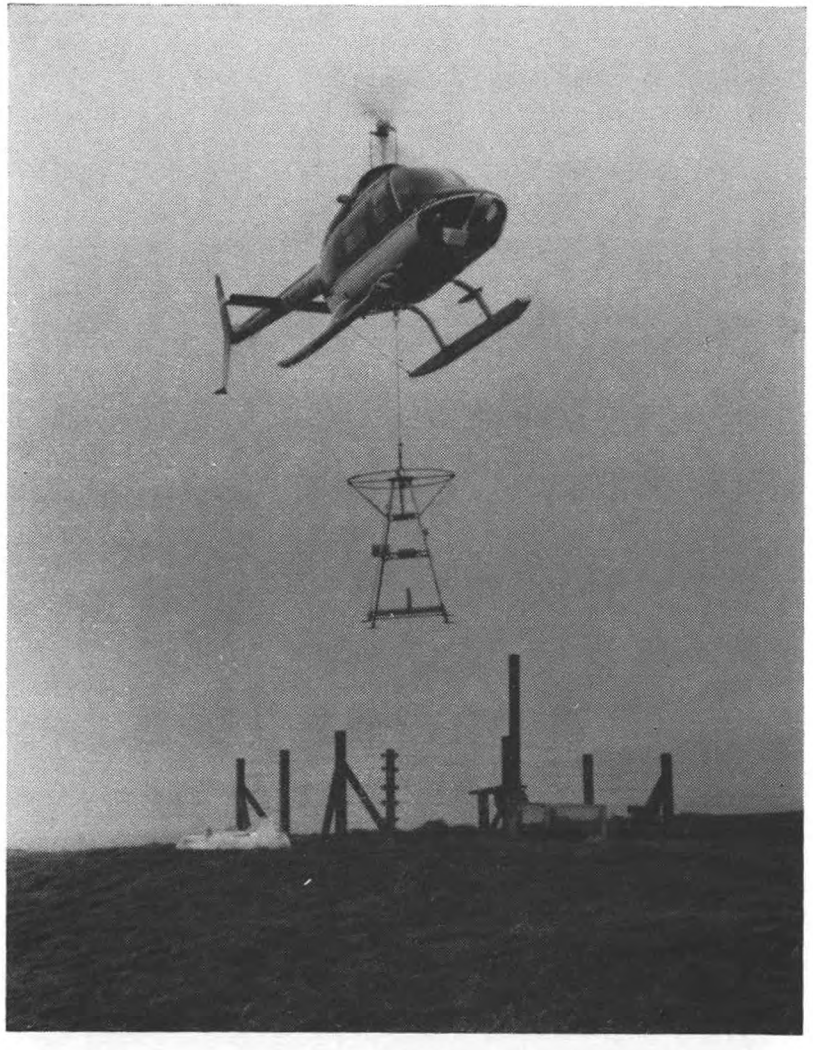
View of western Europe from METEOSAT, obtained from the visible wavelength sensor at 1400 GMT on 27 September 1978.

Spain is clearly visible and the French coast can be traced to Brittany; Cornwall is free of cloud, but the rest of the United Kingdom is largely obscured by broken cloud. The weather on the day was reported at 1200 GMT as broken cloud, generally 3–7 oktas culumus, with showers, particularly in the north.



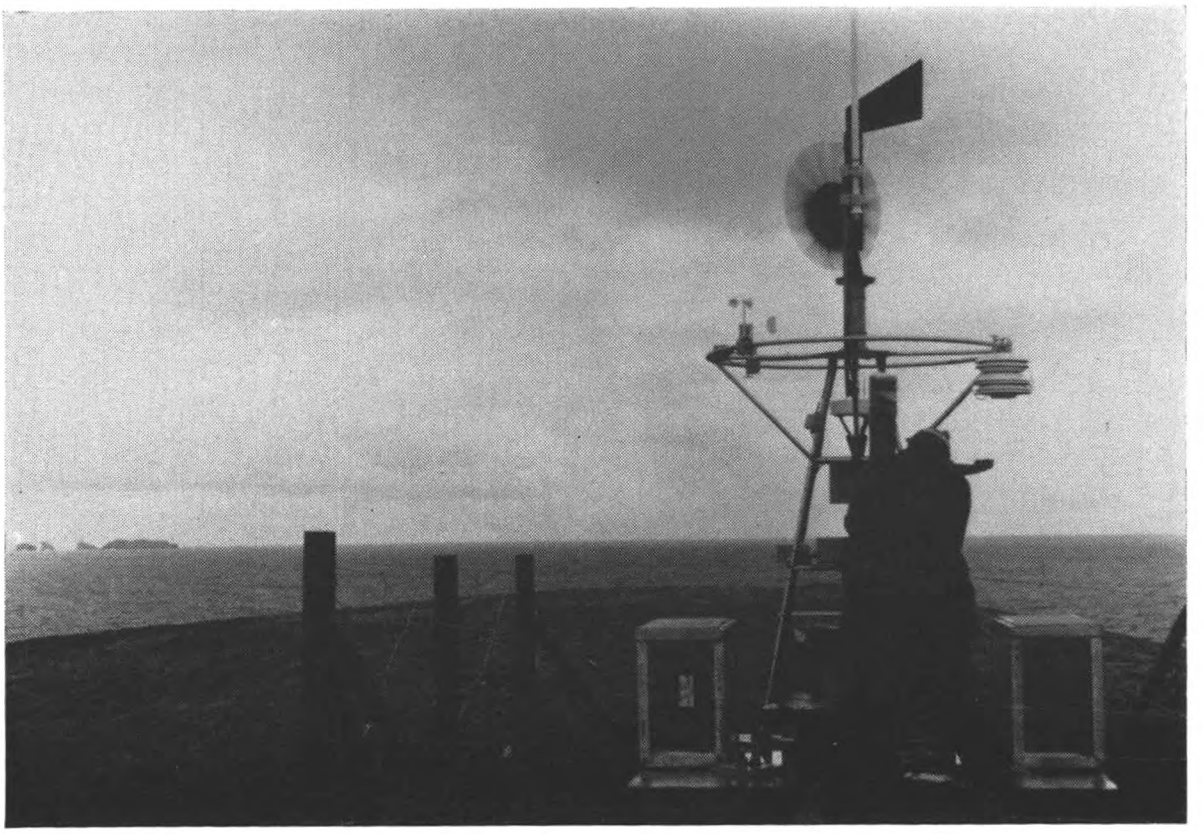
The launch of TIROS-N from Western Test Range (California) on 13 October 1978

(See page 94)



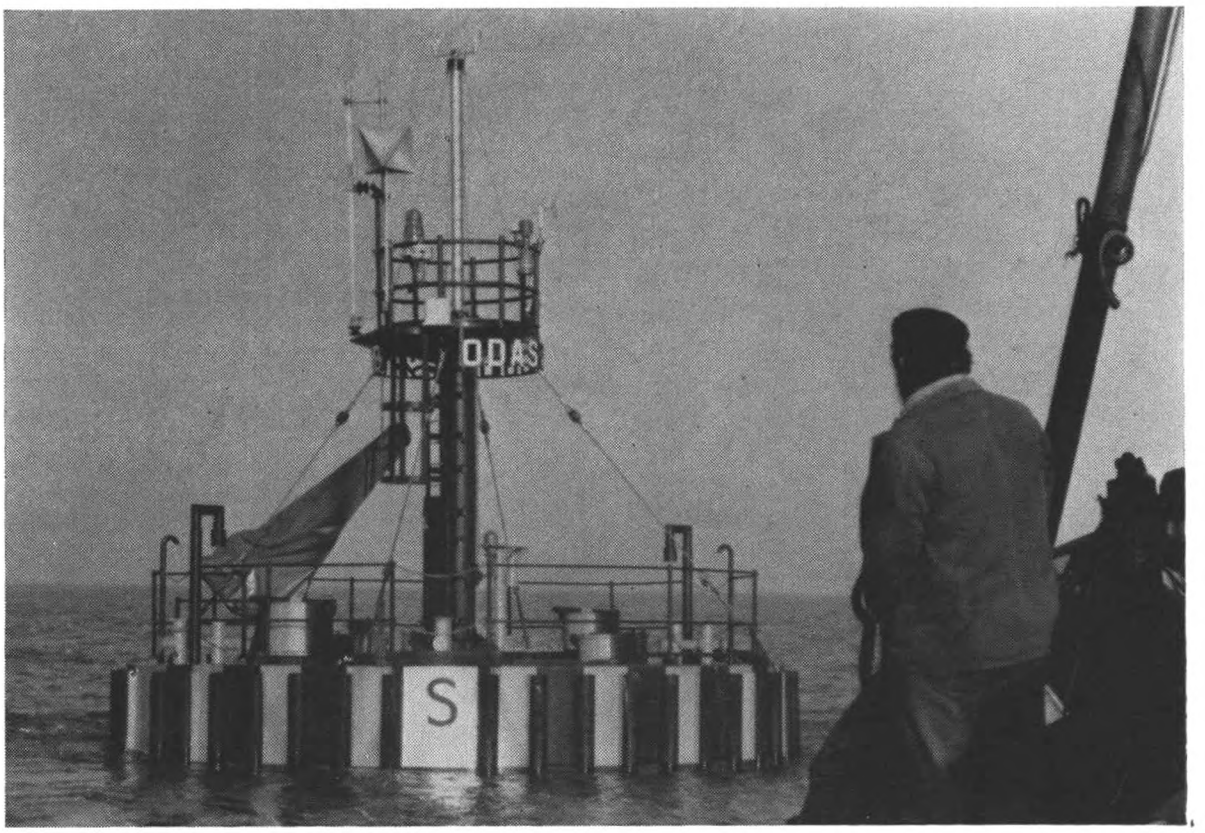
The installation of the automatic weather station on Muckle Holm required the use of a helicopter to land equipment and personnel

(See page 47)



The complete automatic weather station on Muckle Holm undergoing final adjustment after installation

(See page 47)



The national data buoy (DB-1) which is now operating in the South-west Approaches at 48° 40′N, 09° 00′W

(See page 48)

PLATE IV

The Bracknell Shore Station of the North Atlantic Ocean Stations (NAOS) network

The three remote control units for the radio receivers (which are at RAF Bampton) are shown in the background. The use of morse key and earphones to communicate with the ships contrasts with the micro-processor controlled terminal (on the right) for the entry of observations into the telecommunication system, but each represents the most appropriate technology. (See page 62.)

Installation of the automatically opening and closing rain-gauge at Lerwick

The instrument is used to collect precipitation samples for subsequent chemical analysis.
(See page 40)

TABLE XII—AUTOMATIC TELEPHONE WEATHER SERVICE FORECASTS

Information Service Centre	Forecast area	Number of calls 1977	1978
Bedford	40 miles radius of Bedford	285 003	411 205
Belfast	Belfast	306 101	383 287
Birmingham	Birmingham	908 843	1 214 701
Bishop's Stortford	40 miles radius of Bedford	92 581	149 783
Blackburn	Lancashire, Cheshire, Greater Manchester and Merseyside	257 134	319 288
Blackpool	Lancashire, Cheshire, Greater Manchester and Merseyside	170 059	225 162
Bournemouth	South Hampshire	330 008	399 435
Bradford	Leeds, Bradford, Huddersfield	138 812	183 492
Brighton and Hove	Sussex coast	587 268	769 849
Bristol	Bristol	695 439	745 768
Cardiff	Cardiff	421 433	755 991
Canterbury	Kent coast	307 039	509 942
Chelmsford	Essex coast	165 865	166 002
Cheltenham	South-west Midlands	127 407	165 791
Chester	Chester and North Wales coast	145 404	180 055
Colchester	Essex coast	234 213	263 215
Colwyn Bay	Chester and North Wales coast	88 650	111 333
Coventry	Birmingham	310 949	275 811
Derby	Nottinghamshire, Derbyshire, Leicestershire	150 385	170 942
Doncaster	Sheffield, Chesterfield, Doncaster, Barnsley	47 156	61 632
Edinburgh	Edinburgh	361 492	477 568
Exeter	Devon and Cornwall	245 188	315 634
Glasgow	Glasgow	612 114	777 745
Gloucester	South-west Midlands	208 969	276 167
Grimsby	North Lincolnshire and Retford area	53 783	90 334
Guildford	London	150 394	212 115
Hastings	Sussex coast	59 185	95 957
Hereford	South-west Midlands	90 094	120 098
High Wycombe	Thames Valley	118 177	158 035
Huddersfield	Leeds, Bradford, Huddersfield	59 060	100 354
Ipswich	Norfolk and Suffolk	191 585	226 606
Leeds	Leeds, Bradford, Huddersfield	390 761	496 034
Leicester	Nottinghamshire, Derbyshire, Leicestershire	256 943	329 207
Lincoln	North Lincolnshire and Retford area	136 045	206 688
Liverpool	Lancashire, Cheshire, Greater Manchester and Merseyside	355 861	388 496
Liverpool	Chester and North Wales coast		54 023
London	London	3 216 033	4 207 551
London	Essex coast	159 315	179 497
London	Kent coast	186 819	226 647
London	Sussex coast	339 615	403 825
London	Thames Valley	192 662	269 341
London	40 miles radius of Bedford	120 779	184 711
Luton	40 miles radius of Bedford	203 270	287 180
Manchester	Lancashire, Cheshire, Greater Manchester and Merseyside	696 905	798 054
Manchester	Chester and North Wales coast		95 894
Medway	Kent coast	236 419	372 401
Middlesbrough	North-east England	176 044	225 957
Newcastle	North-east England	412 266	534 089
Newport, Gwent	Chepstow, Castleton, Tredegar	72 262	112 859
Northampton	40 miles radius of Bedford	29 567	57 701
Norwich	Norfolk and Suffolk	302 499	432 653
Nottingham	Nottinghamshire, Derbyshire, Leicestershire	468 769	531 263
Oxford	Thames Valley	273 681	307 310

Information Service Centre	Forecast area	Number of calls 1977	1978
Peterborough	40 miles radius of Bedford	97 674	142 565
Plymouth	Devon and Cornwall	494 229	561 279
Portsmouth	South Hampshire	425 738	475 598
Reading	Thames Valley	349 995	433 776
Sheffield	Sheffield, Chesterfield, Doncaster, Barnsley	400 987	470 898
Southampton	South Hampshire	546 293	612 480
Southend	Essex coast	259 263	337 662
Southport	Lancashire, Cheshire, Greater Manchester and Merseyside	51 643	68 716
Swindon	Bristol	44 268	62 697
Torquay	Devon and Cornwall	137 322	163 430
Tunbridge Wells	London	86 897	123 900
Total		19 040 617	24 467 679

TABLE XIII—CLIMATOLOGICAL ENQUIRIES

Met O 3, Met O 8, Edinburgh and Belfast receive a number of enquiries relating to past weather, to climatology and to the application of meteorological data to agriculture. The following figures give the total number of enquiries and the percentages of this number in various categories.

	1977	1978
Total number of climatological enquiries	28 986	33 283
Percentages relating to:		
agriculture (farming, forestry, market gardening)		9·7
building and design (including siting)		23·2
commerce (sales, marketing, advertising)		3·2
drainage		2·1
education and literature		5·4
flooding		0·3
heating and ventilation		3·9
industrial and manufacturing activities		4·4
law (damage, accident, insurance)		12·6
medical and health		0·7
press and information centres		2·1
research		8·5
sport, hobbies, holidays		0·9
transport and communications		2·4
water supplies		8·7
miscellaneous (purpose known)		7·2
miscellaneous (purpose unknown)		4·7

TABLE XIV—DATA PROCESSING

(a) Punched-card installation

Number of cards punched by the Meteorological Office installation 276 000

Number of cards punched elsewhere on behalf of the Meteorological Office... 85 519

(b) Processor-controlled keying system

The processor-controlled keying (PCK) system was used for data preparation during 1646 hours.

(c) Computer installations

(1) The 360/195 computer was used for computing during 8523 hours.

(2) The 370/158 computer was used for computing during 8581 hours.

TABLE XV—INSTRUMENT TESTING, CALIBRATION AND ACCEPTANCE

	Number of tests or calibrations
General meteorological instruments:	
Wind measuring	889
Pressure measuring	1320
Humidity measuring	81
Precipitation measuring	449
Radiation measuring	510
Sunshine recording	127
Temperature measuring	4171
Miscellaneous	1877
Electrical/electronic instruments and systems	1126
Electrical/electronic components	1237
Balloons	29 364
Radar reflectors	35 500
Radiosonde parachutes	4350
Radiosonde unwinders	1960
Mk 2B radiosondes calibrated	154
Mk 2B radiosonde recoveries received	162
Mk 3 radiosonde component parts tested and accepted	30 072
Mk 3 radiosonde humidity transducers skinned and seasoned	9020
Mk 3 radiosonde pressure transducers calibrated	7000
Mk 3 radiosonde pressure reference elements calibrated	5950
Mk 3 radiosonde recoveries received	1034
Total	136 353

DIRECTORATE OF RESEARCH

SPECIAL TOPIC—RESEARCH IN TROPICAL METEOROLOGY AND ITS RELEVANCE TO THE GENERAL CIRCULATION

Introduction

For a long time our knowledge and understanding of tropical meteorology has lagged behind that of middle and higher latitudes. There are a number of reasons for this. Most important is the lack of observations which are a prerequisite for developing understanding. Although surface wind conditions over the tropical oceans have been known about and documented since the 17th century, mainly, in the early years, as a result of the voyages of sailing ships, and observations of surface conditions over land are also available for a large number of locations, observations to depict the upper atmosphere are much more recent in origin, and for the tropics, the number of stations making them is still far from adequate. A global map showing stations which have a program to observe upper wind, temperature and humidity at least once a day is shown in Figure 4. The distribution is clearly far from being optimum. There is a clustering in densely populated regions where there has been a need for upper-air information particularly for aviation. On the other hand there is a general lack of observations over the oceans, where there are only a handful of weather ships, and over the less developed countries. Not only do the tropics have a much poorer observational network than middle latitudes, but there are difficulties caused by inadequate telecommunication facilities which result in many of the observations never reaching the meteorological centres where they could be used on a day-to-day basis and stored for investigational purposes.

The other reason for the lack of understanding of tropical meteorology is that the atmospheric motions there are quite different from those experienced in higher latitudes. Many of the rules for analysing and predicting the weather, developed subjectively at first but increasingly scientifically based in recent years, become less applicable as the equator is approached. The difference can be attributed mainly to the effects of the earth's rotation. Motions within the atmosphere are mainly horizontal and they are greatly influenced by the component of the spin of the earth about the vertical. Since the earth rotates about an axis through the poles, the vertical component of spin at the equator vanishes and the motions are characteristic of a non-rotating fluid. At middle and high latitudes, however, the effect of rotation is strong. In the presence of horizontal temperature contrasts, this provides the conditions for the development of large-scale depressions and anticyclones. They are associated with pronounced horizontal variations of pressure, wind flows that are generally along the isobars, and wind speeds that are proportional, to a first approximation, to the pressure gradient. Wind and pressure fields having these relationships are described as being in geostrophic balance. Near the equator the motions are very different. In comparison with middle latitudes, pressure gradients are usually weak, and the winds are generally less coherent in space and time. The motions tend to be either those associated with the Intertropical Convergence Zone (ITCZ), or those caused by surface heating contrasts. The ITCZ is a

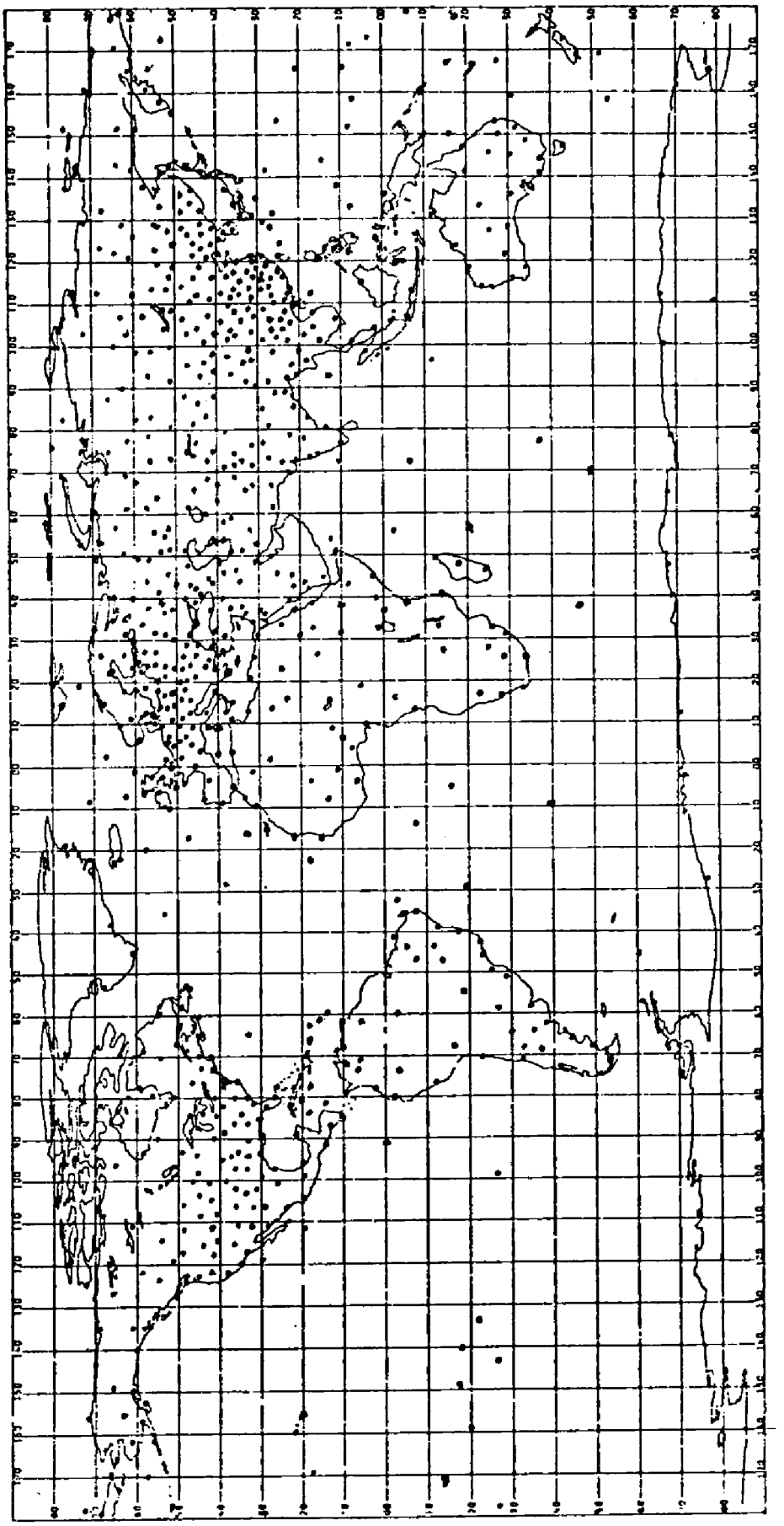


Figure 4—Global distribution of stations making observations of upper-air temperature, wind and humidity at least once a day

narrow region of clouds and rain where air masses originating in the two hemispheres converge; it can often be traced continuously round most of the tropical belt. The annual weather pattern of many tropical regions is dominated by its seasonal migration north and south. Differences in surface heating lead to motions primarily on two distinct scales. On large scales the heating contrast between continents and oceans is the mechanism for creating the monsoons of West Africa and India. On small scales buoyancy forces give rise to convection whose effects are observable as cumulus or cumulonimbus clouds. The concepts underlying weather forecasting in middle latitudes are mostly inapplicable in the tropics. Advances in the ability to predict in this area depend on obtaining an adequate observational account of the atmospheric motions.

The lack of adequate understanding of tropical meteorology has important implications that extend far beyond the tropics. Considering the earth as a whole, the main energy input is in tropical regions. Motions in the atmosphere and in the oceans then exchange heat between latitudes, so that low and high latitudes are respectively colder and warmer than they would otherwise be. This is very important for the British Isles for example, where the climate is moderated by frequent south-westerly winds and by warm ocean currents in the North Atlantic. For an adequate description of the general circulation of the atmosphere it is clearly essential to understand the role of the tropics and particularly how energy is transferred to other regions. Even for forecasting for middle latitudes beyond a period of a few days, it is important to include the interaction between middle latitudes and tropical systems.

Until recently, the Meteorological Office had a considerable operational responsibility in the tropics, mainly in support of RAF bases overseas. Research was directed towards helping the operational requirement. There was, for example, work on practical analysis and forecasting in particular localities, and analysis of radar and aircraft data to quantify the hazard of tropical cumulonimbus cloud to aviation. A number of research papers were produced by forecasters drawing upon their operational experience in tropical conditions. With the withdrawal of United Kingdom personnel from military installations overseas there has been a changing emphasis in Meteorological Office interest. It has coincided with a changing view of the tropics by meteorologists generally. The growing awareness of the need to treat the global atmosphere as a single entity and the lack of understanding of how the tropics fit into the overall scheme have led to an unprecedented concentration of research activity on the mechanisms of tropical systems. During the last few years the Meteorological Office has contributed significantly to this research, which is necessary for an understanding of global climate and for long-range weather prediction.

Research related to GARP Atlantic Tropical Experiment

The importance of an improved understanding of tropical meteorology was recognized at an early stage in the planning of the Global Atmospheric Research Program (GARP) and a special sub-program, the GARP Atlantic Tropical Experiment (GATE), was organized. This was designed primarily to study the physical properties of convective systems over a region of the tropical Atlantic and in particular the ways in which small convective elements are organized into large cloud clusters and the ways in which these large clusters interact with atmospheric motions on still larger scales. For example over West Africa the horizontal wind field in the lower troposphere is found to contain waves

which propagate westward in the large-scale easterly flow. Convective activity occurs preferentially in certain parts of these waves and probably contributes to their development, while the waves themselves almost certainly interact with the large-scale wind field. The experiment was also intended to provide data against which the validity of numerical weather prediction methods could be tested in the tropics. In what was probably the largest international experiment ever undertaken, ten nations collaborated during the period June to September 1974 to measure properties of the atmosphere over the eastern tropical Atlantic in much greater detail than had previously been attempted. Thirty-nine ships, 13 research aircraft, several meteorological satellites and some 5000 personnel were involved. The site was chosen for its suitability for the study of African waves and associated convective activity discussed above.

The United Kingdom's contribution to GATE took various forms. The comprehensively equipped Hercules aircraft of the Meteorological Research Flight flew many missions during the field phase, and 4 out of the total of 39 weather ships were British. Following the field phase 5 different centres around the world had responsibility for processing the many observations accumulated during the experiment. The Meteorological Office undertook the data management activities of the Synoptic Sub-program.

A tropical modelling group has existed within the Meteorological Office since 1973. It was set up to take advantage of the unique source of data provided by GATE and so provide an improved understanding of tropical meteorology for numerical modelling of the general circulation. During GATE, the group ran a near-real-time forecasting experiment to provide essential background to the research.

The tropical model. The tropical research group has developed and used a numerical model of a limited area of the tropics, including the site of GATE. It was adapted from a global general circulation model. Figure 5 is a diagramatic representation of the basic structure. The horizontal resolution is approximately 220 km, grid points being located on a regular mesh at 2° latitude and longitude intervals. In the vertical there are 11 data levels. They are distributed so as to provide concentrations near the bottom of the atmosphere and near the tropopause (approximately 15 km). This provides enhanced resolution where important atmospheric processes are known to take place on a relatively small vertical scale. The total number of grid points is 18 304. At each point, values of horizontal wind, temperature and humidity are held. In addition, surface values of pressure and temperature are carried. Mathematical equations (based on Newton's laws of motion and the first law of thermodynamics) are solved numerically at each grid point at each successive time step of $7\frac{1}{2}$ minutes. To advance 24 hours in this way requires approximately 10^{10} basic arithmetic operations, or approximately 10 minutes of computing time on the Meteorological Office IBM 360/195 computer. In addition to solving the dynamical equations, other physical processes have to be taken into account. The importance of convection has already been mentioned; additionally the processes by which the atmosphere interacts with the underlying land or sea, and with short- and long-wave radiation have to be included. They are incorporated in the model by 'parametrization', which implies that the aggregate of all subgrid-scale processes is represented on a statistical basis in terms of the model variables available at the grid points; the development of parametrization schemes is a very important part of atmospheric numerical modelling. The height of land

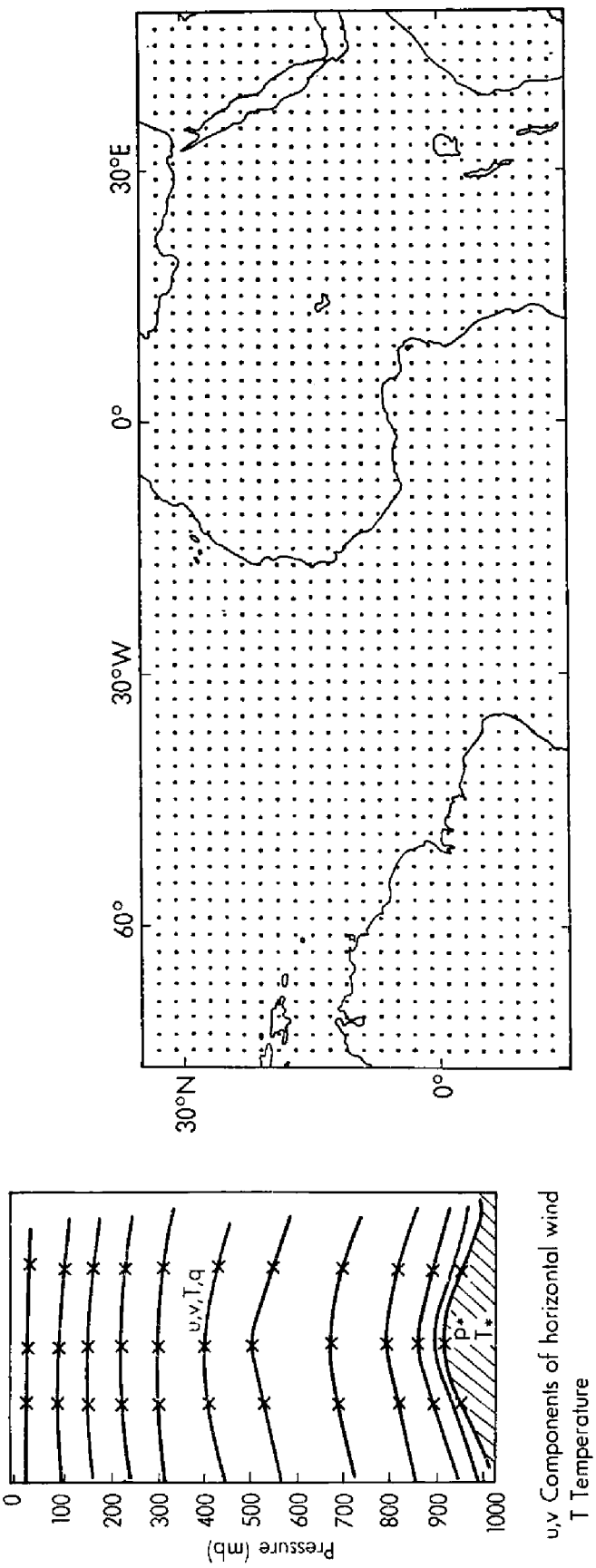


Figure 5—Vertical and horizontal structure of the tropical model

areas above sea level is specified and used in the model equations; the effects of underlying terrain may be important to meteorological developments. Over land, soil moisture content and surface albedo are taken into account. Sea surface temperatures are held fixed, since typically they change more slowly than atmospheric variables. The limited-area model has lateral boundaries, where boundary conditions have to be specified; they are that the variables there do not change during the forecast period. This introduces errors which spread inwards from the boundaries as time progresses and make forecasts for more than a few days ahead of little value. The model has been used typically for predictions of a few days ahead, the initial conditions being based on GATE data for a particular occasion.

Objective analysis. For forecasting purposes observations have to be analysed and presented as values on a regular grid. The choice of the best method of spatial interpolation (or 'objective analysis') of temperatures and winds (and humidities, which are treated separately) poses considerable problems, especially in the tropics where the winds provide only a limited guide to the temperature field and vice versa. The objective analysis scheme for routine weather prediction in middle latitudes employs the geostrophic relation to maximize the information from wind and temperature observations and therefore cannot be used in the tropics. For the tropical model a new analysis scheme was developed. It uses 'optimum interpolation', which is based on formulae derived from the minimization of the root-mean-square error in a long series of analyses. Account is taken of the different accuracies of the measurements; for example, surface pressure can be measured more accurately over land than on a moving weather ship and upper winds can be determined more accurately be tracking a radiosonde balloon than by deducing them from the movement of clouds between successive satellite photographs. The process of analysis for a particular time starts from a previous numerical forecast (perhaps starting from 24 hours earlier), valid at that time. It is usually a good first approximation to the atmospheric state, being particularly helpful in data-sparse areas. Optimum interpolation is then carried out independently for the horizontal wind and for the temperature (or more precisely the geopotential height, which depends on temperature). In latitudinal extent the tropical model includes the equator, where the geostrophic relationship breaks down completely, and 35°N where the relationship is generally quite valid. To provide some degree of compatibility between wind and temperature fields the separate analyses of the two variables are followed by a process of 'variational adjustment' during which the fields are altered in such a way as to bring them more nearly to a balanced, geostrophic state. An example of an analysed wind field is shown in Figure 6, which depicts the airflow at a height of approximately 1·5 km for 12 GMT on 4 September 1974. Wind arrows are shown at each grid point. The general direction of the main flows are emphasized by the full black lines. The position of trough lines in the main easterly flow are shown as dashed lines. The chart gives a good indication of the scale of the wave disturbances that characterize the tropical Atlantic at this time of year.

Numerical forecasts. The objectively analysed fields were used as initial data for numerical forecasts which have been verified against subsequent observations and analyses. Results have been encouragingly good. The 24-hour predictions of wind fields in the lower troposphere, where the temporal variability is greatest, generally indicate the movement and development of easterly waves

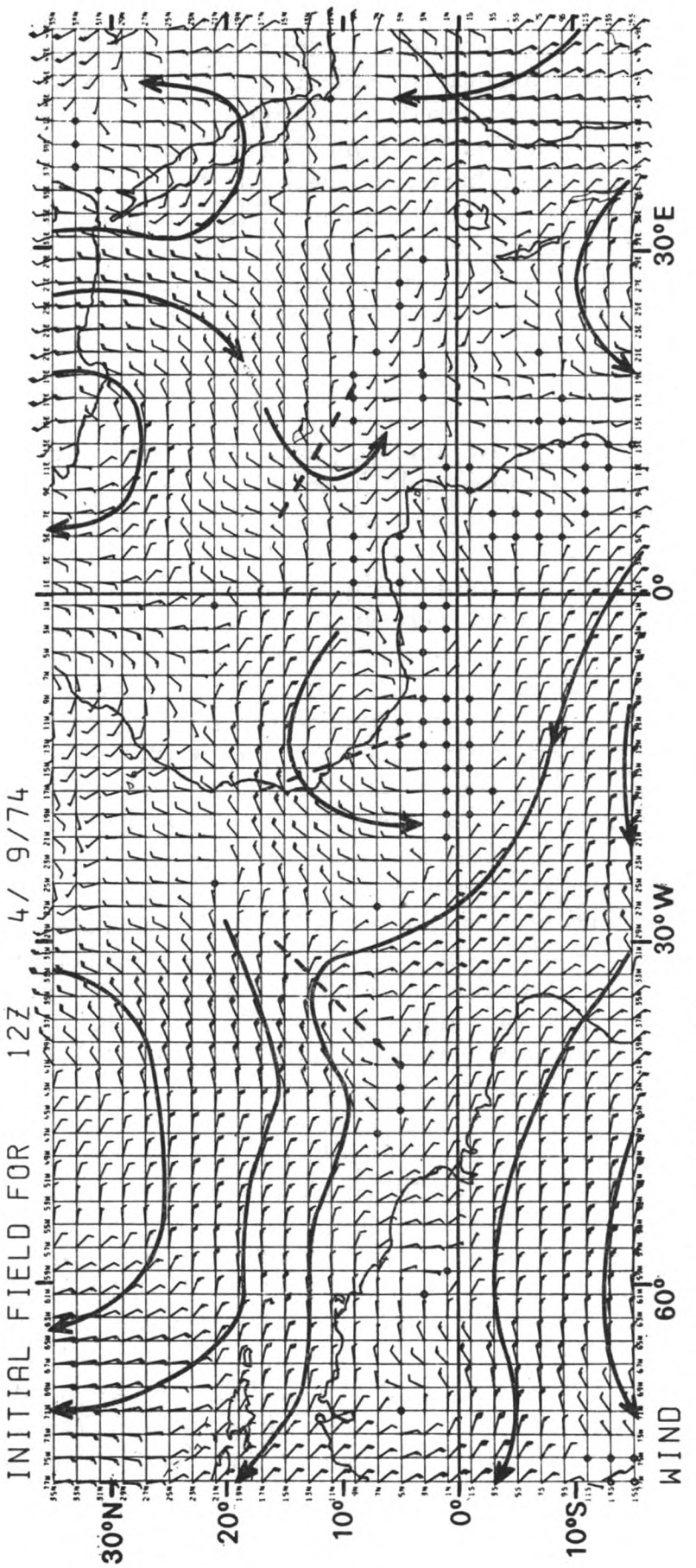


Figure 6—An initial field of horizontal wind at approximately 1·5 km

correctly. The predicted rainfall patterns are fairly realistic and the amounts are also reasonable. Qualitative assessment of such features as storm-centre movement and rainfall suggest a forecasting quality comparable with operational numerical weather predictions for middle and high latitudes. These results, which are consistent with similar types of studies being done in the USA, represent a considerable advance in tropical forecasting since it is only in the post-GATE period that numerical models have been shown to have substantial predictive skill. It should, however, be remembered that the forecasts started from initial conditions derived from an unusually dense network of observations. In normal conditions lack of sufficient observational data remains a major problem.

Since GATE itself took place in 1974, the analysis and forecast procedures have been improved. Now that a complete set of observational data are available the objective analyses are being repeated to provide the best possible descriptions of the atmosphere during the experiment. These can then be used for testing further revisions of the formulation of the physical and dynamical processes in the numerical model.

Convection. The importance of tropical convection in transferring heat and moisture from the surface into the troposphere and the need to represent this process in numerical models by parametrization in terms of the explicit variables has already been discussed. The original parametrization adopted with the tropical model has been used for some time in general circulation studies. The method is essentially to examine adjacent vertical layers at each grid point to establish if a condition of convective instability exists. If it does then exchanges of heat and moisture between the layers are made, the extent of the exchanges being dependent on the degree of instability. In this mixing process, phase changes of moisture are permitted; rainfall may or may not be produced. The method is effective in that it acts to stabilize the model's atmosphere and to transfer energy upwards. It does not, however, simulate very effectively the process of deep convection in which a convective tower may transfer air parcels from the surface to the lower stratosphere almost undiluted by environmental air.

With this scheme the tropical model met with some success in forecasting rainfall. Verification is easier over land, where rainfall amounts are more accurately measured, than over the sea. During GATE much of the rain over Africa fell in the latitude band 5–10°N. A sequence of forecasts for a period in September 1974 produced successfully the observed alternation of wet and dry periods, with broad agreement in the location and intensity of rainfall maxima and minima. Rainfall predictions were poor, however, when the predictions of wave movements were also poor. A serious weakness of the scheme was that it caused unrealistic storms to develop over parts of Africa and South America with incorrect wind circulations and excessive rainfalls.

To improve the simulation of convective processes, a new parametrization scheme has been developed which provides a more explicit representation of the deep convection occurring in cumulonimbus clouds. In this scheme air entering the clouds near the earth's surface can be transported through the depth of the troposphere and detrained 15 km up, near the tropopause. On the way it is modified by the entrainment of drier, cooler air from outside the clouds. A general compensating sinking of the surrounding air takes place and detrainment can occur at any level to represent the decay of smaller, less

buoyant clouds. The efficacy of the scheme depends on suitable specifications of such parameters as the mass of air entering the clouds, the rate of entrainment, the initial temperature excess of the parcel above that of the model environment and the extent to which precipitation evaporates while falling through lower layers.

The new scheme gives better rainfall forecasts and it reproduces the observed vertical variation of temperature in the tropical atmosphere more accurately. Predictions of easterly wave development and movement have also been encouraging. Figure 7 shows the results of an 8-day integration of the tropical model using the new convective parametrization. The diagram compares the movement (observed and predicted) of the trough lines of the easterly waves across the tropical Atlantic. The predicted evolution is very close to that observed. The success of the procedure for simulating deep convective processes, hitherto tested in the tropics only, has prompted the incorporation of a similar formulation in a global model.

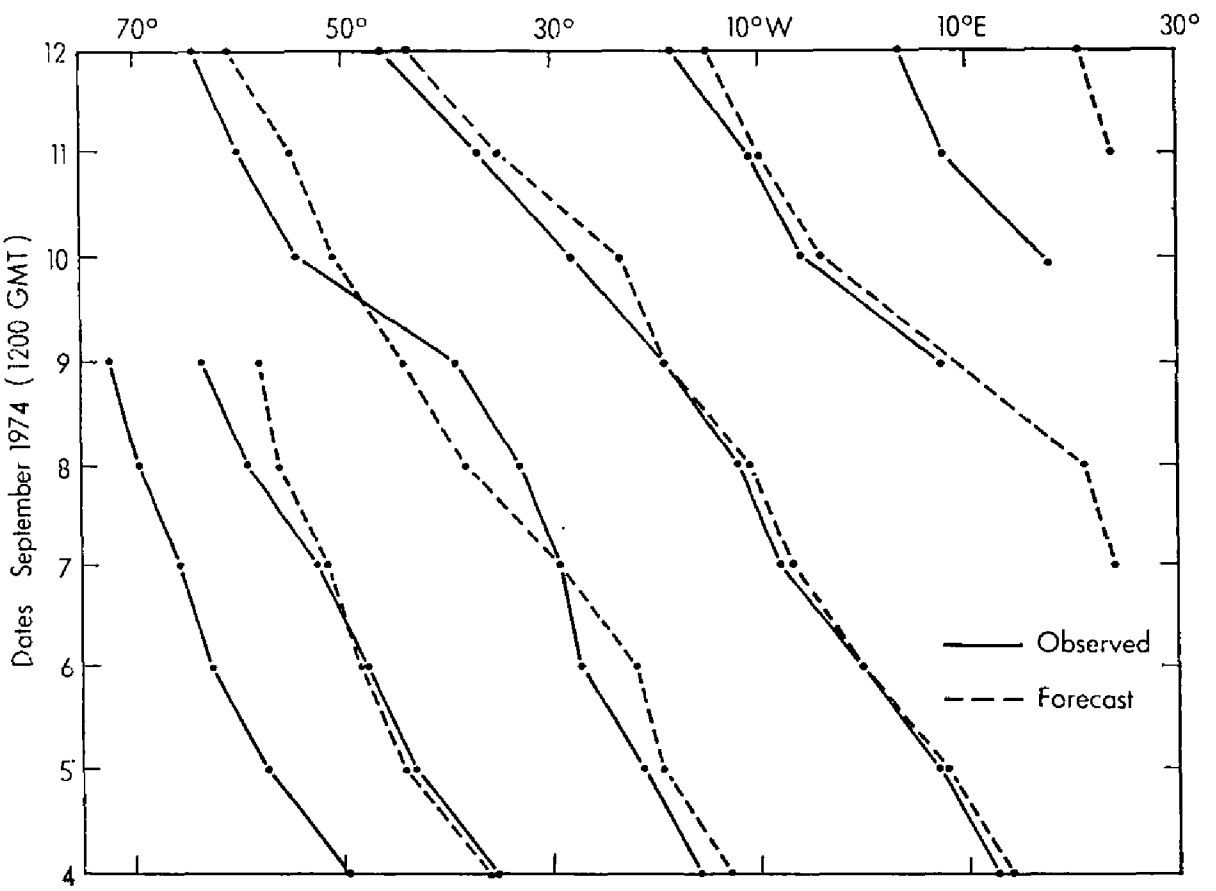


Figure 7—850 mb trough positions at approx. 13°N as observed, and as predicted, in 8 day forecast from 12 GMT on 4 September 1974

Radiation. Radiative processes in the atmosphere are both important and complicated. Solar radiation absorbed directly by the atmosphere, or absorbed at the earth's surface and then transferred into the atmosphere, is the source of energy for atmospheric motions. However, the distribution of radiation at the earth's surface depends on the cloudiness and convective clouds which usually form as a result of heating at the earth's surface, reflect and absorb part of the incoming solar radiation, so reducing the amount reaching the surface and

inhibiting further cloud development. This interaction between radiation and cloud may have larger-scale effects, particularly in the tropics where radiative and convective processes are relatively intense.

There is a variety of cloud types with differing modes of formation and dissipation, some of the processes involved being better understood than others. Stratocumulus, for example, has been studied observationally and is relatively well understood. Far less is known about the formation and dissipation of middle and high level cloud. Synoptic systems whose overall structures appear very similar may have quite different upper clouds. A thin layer of altostratus can have a very marked effect on the atmosphere's radiative balance but it is often difficult to relate its occurrence to other atmospheric processes.

It is evident that the simulation of radiation within a numerical model should include its interaction with cloud and within numerical models this requires the ability to predict cloud amount, type and vertical extent. However, the formulation of these complex processes numerically poses considerable problems and in the experiments described so far a simplified approach was adopted. The incoming solar radiation and atmospheric long-wave radiative cooling were expressed as functions of latitude based on studies with climatological data. This method, essentially non-interactive, ensures a reasonable representation of radiative effects in a generalized sense. Recently progress has been made with the development of an interactive scheme. The procedure depends on the model's ability to predict details of the cloud amount, height and thickness over the forecast region. Cloud amount is not a basic variable and must therefore be expressed in terms of other parameters that are available. Studies have been made with a four-category cloud specification—low level, medium level, high level and convective. Within this classification the height and thickness of cloud layers may vary. The presence of convective cloud can be linked to the occurrence of convection within the model. Cloud coverage for the other three types are expressed as functions of the model's humidity and temperature structure.

The interactive radiation scheme has been applied in the tropical model and compared with earlier results. Substantial differences in rainfall and circulation predictions occurred over a three day period. Over land increasing cloudiness reduced the solar radiation reaching the ground and so reduced convective rainfall. Over the sea interactive cloud increased rainfall and intensified wave development. These differences are partly attributable to the fact that the sea surface temperatures, unlike the land values, show little sensitivity to variations in incoming solar radiation.

The south-west monsoon region

Having examined one region of the tropical atmosphere in connection with GATE it is of interest to see to what extent features peculiar to other tropical regions can be simulated. By a displacement eastwards through 90° of longitude the tropical model is conveniently positioned over the Indian subcontinent and surrounding area. With appropriate changes to the model's underlying surface conditions (sea surface temperatures, topography, albedo and soil moisture content), and using appropriate observational data it is possible to use the numerical analysis and forecast procedure to examine some characteristic features of the south-west monsoon. The weather systems of this region pose special problems. The monsoonal reversal of airflow which affects a large

fraction of the globe is a major feature of the atmospheric general circulation. It occurs as a response to the corresponding reversal of thermal contrasts at the earth's surface. During the northern hemisphere winter the Asian land mass is cold relative to the Indian Ocean to the south. The temperature contrast is transmitted to the atmosphere above and such thermal contrasts induce pressure gradients with associated large-scale flow patterns. During the summer months this contrast is reversed. The Asian land mass quickly responds to increased solar heating; the ocean to the south, with a much higher thermal capacity, undergoes a much smaller temperature increase and the pressure gradients in the atmosphere are essentially reversed. In practice several other factors are relevant to an understanding of this major seasonal wind reversal.

The majority of meteorological studies of the region have concentrated on the summer phase of the monsoon, with its associated heavy rainfalls. Over the Indian subcontinent the onset of the summer monsoon is typically marked by an increase of rainfall towards the end of May. Surface south-westerly winds are established over the Arabian Sea carrying a plentiful supply of moisture towards the Indian land mass. The advance of the monsoon proceeds from south-east to north-west across the subcontinent and by early July most of the region is experiencing rainy conditions. From July onwards with the monsoon circulation fully established there is an increasing tendency for depressions to develop over the Bay of Bengal and move inland over Bangladesh and India. Several such depressions may form during the monsoon season and they are associated with particularly heavy rainfall though only occasionally do they become sufficiently deep to be classified as tropical storms. The limited-area tropical model is not suited to studying such matters as the onset and maintenance of the monsoon, since this is a very large-scale phenomenon with a relatively long time-scale. It is, however, suitable for studying Bay of Bengal depressions and the mechanisms which determine their formation and movement. There are several differences between Bay of Bengal depressions and the disturbances over the tropical Atlantic. Firstly the depressions form over the sea and then move inland, the converse of developments over West Africa and the Atlantic. This movement of the depressions over land is believed to be the factor which inhibits further development to hurricane strength, since it reduces the supply of moisture from the underlying surface. Secondly the depressions form at higher latitudes, typically around 20°N rather than 10°N. Thirdly orographic influences are more evident over India than West Africa, with the Himalayas providing an effective northern boundary to the progress of the depression. Because of these differing circumstances it is of interest to examine the model's simulation of Bay of Bengal depressions, and numerical integrations have recently been carried out for this purpose. Choosing a particular occasion when a depression could be traced over the Indian subcontinent (data coverage being better over land than sea) a daily sequence of objective analyses and short-range numerical forecasts (one or two days) have been produced. The results showed the model to be capable of deriving forecasts in which the depression moves in a realistic manner, with reasonable rainfall predictions. So far it has been less successful in reproducing the earliest stage of the development of these depressions. Indeed one of the main difficulties is that over the Bay of Bengal there is a lack of observations, especially in the upper air, necessary to identify the conditions favourable to development. Studies of the monsoon area would greatly benefit from a period of intensive

observation, such as that over the tropical Atlantic during GATE. Such a project, albeit with fewer resources, is scheduled for 1979. The Monsoon Experiment (MONEX) will bring together the resources of many member nations of the World Meteorological Organization in an attempt to study the structure of Bay of Bengal depressions and other monsoon problems in greater detail than has previously been possible. Among the other problems to be examined are the physical processes influencing the onset of the monsoon; the causes of the marked variation from year to year in the intensity of the monsoon; the importance of surface heating and of orographic effects in determining the monsoon circulation and the interaction of the monsoon with middle-latitude systems. When the additional observations planned for MONEX are received they can be used in the limited-area model experiments to provide better initial representations of the atmospheric state. Present studies over the monsoon region continue, and are directed particularly to understand the differences between developments as predicted using the limited-area model and those in this same region using a global general circulation model.

Applications to forecasts for the United Kingdom

By successive displacement of the limited-area model it is possible to cover the complete tropical belt, section by section, so providing analyses from 15°S to 35°N. The operational objective analysis scheme used in the Central Forecasting Office is designed for middle and high latitudes and covers a region from the north pole down to approximately 19°N. By applying the two analysis schemes to their respective regions composite analyses covering the full northern hemisphere and continuing down to 15°S may be created. In the region of overlap between 19°N and 35°N the two analyses are combined in a simple way to avoid discontinuities that may arise between the two systems. Merged analyses extending to 15°S have been found useful in five-day numerical prediction experiments. In forecasting for the British Isles it seems that the benefits of using a larger analysis area may depend on the prevailing meteorological conditions. If the atmospheric flow is predominately westerly then the benefits may well be small, but on occasions with a substantial north–south component of flow the influence of events in the tropics spreads to middle latitudes within the five-day period.

General circulation models

The foregoing discussion has concentrated on the use of limited-area models in the tropics. The tropical modelling research group is part of the Dynamical Climatology Branch, whose main concern is the use of global models to study the general circulation of the atmosphere. Indeed much of the work with the tropical model has been designed to provide a test bed for parametrization schemes that can be subsequently applied in the global models. Consequently it is appropriate to examine the extent to which the general circulation models successfully simulate the tropical atmosphere. The results examined to date are of integrations of the models run typically for 50 (simulated) days. They do not necessarily require real initial conditions from which to start. It is feasible to start with the model atmosphere in some idealized state (perhaps zero wind and uniform temperatures). After the model has been integrated forward in time for a reasonable period the radiative and other heat-exchange processes will have acted upon the model atmosphere and the model establishes its own

'climatological' state. Integrations that have received most attention to date, in terms of their performance in the tropics, have been simulations assuming values of sea surface temperature and of solar radiation appropriate to July, with assessment of results being concentrated in the south-west monsoon region. Realistic representation has been achieved of the large-scale wind regime over the monsoon region. Important features in this respect are the low-level cross-equatorial jet along the East African coast; the broad south-westerly flow over the Indian Ocean; the so-called monsoon trough over the Bay of Bengal and north India, and the very strong easterly flow observed in the upper troposphere. Figure 8 shows the pattern of flow in the lower troposphere averaged over 30 days, as computed by the model. The simulations are on the whole good though there are errors in intensity. Rainfall predictions are less satisfactory particularly over north-east India where the failure to develop Bay of Bengal depressions produces a marked rainfall deficiency. The model produces realistic simulations of other transient features in its day-by-day evolution. In particular the variations in intensity and orientation of the East African jet are in reasonable accord with observations. Similar assessments of the model's performance in other tropical regions are currently taking place.

Another application of general circulation models has been to study the effect of large-scale anomalies of sea surface temperatures in the tropics. Past observations have suggested that unusually warm sea surface temperatures in tropical regions can have marked effects on atmospheric flow not only in the region of the anomaly but also in middle and high latitude regions. Noting that in the present model simulations the sea surface temperature is unchanging with time it is a simple matter to introduce anomalies at the start of a particular integration and then to compare the results with a control run which used normal climatological values. Results of experiments with realistic anomalies (typically of about 2 °C) introduced into the east Pacific do indeed show significant changes in the meteorological fields in middle and high latitudes, the sense of which is consistent with observed changes. Similar experiments considering anomaly fields not only of sea surface temperatures but also of surface albedo, soil moisture content and cloudiness may well provide useful information for long-range weather forecasting.

Conclusion

There is a need to understand the tropical atmosphere because it profoundly affects the general circulation of the atmosphere as well as playing some part in determining the weather in middle latitudes a few days ahead and, of course, being of vital importance to those living in the tropics. GATE provided a unique opportunity, in which the Office participated fully, to obtain a detailed set of observations in one region of the tropics. These observations have provided a strong impetus to studies in tropical meteorology in many countries. In the Office, studies have concentrated on the development of numerical models. These have been developed to the point where their forecasting ability, given adequate initial observations, is similar to that of models for higher latitudes. Development of the models is continuing, with the help of GATE data, to ensure that the tropics are properly represented in studies of the general circulation and in forecasting the weather of middle latitudes.

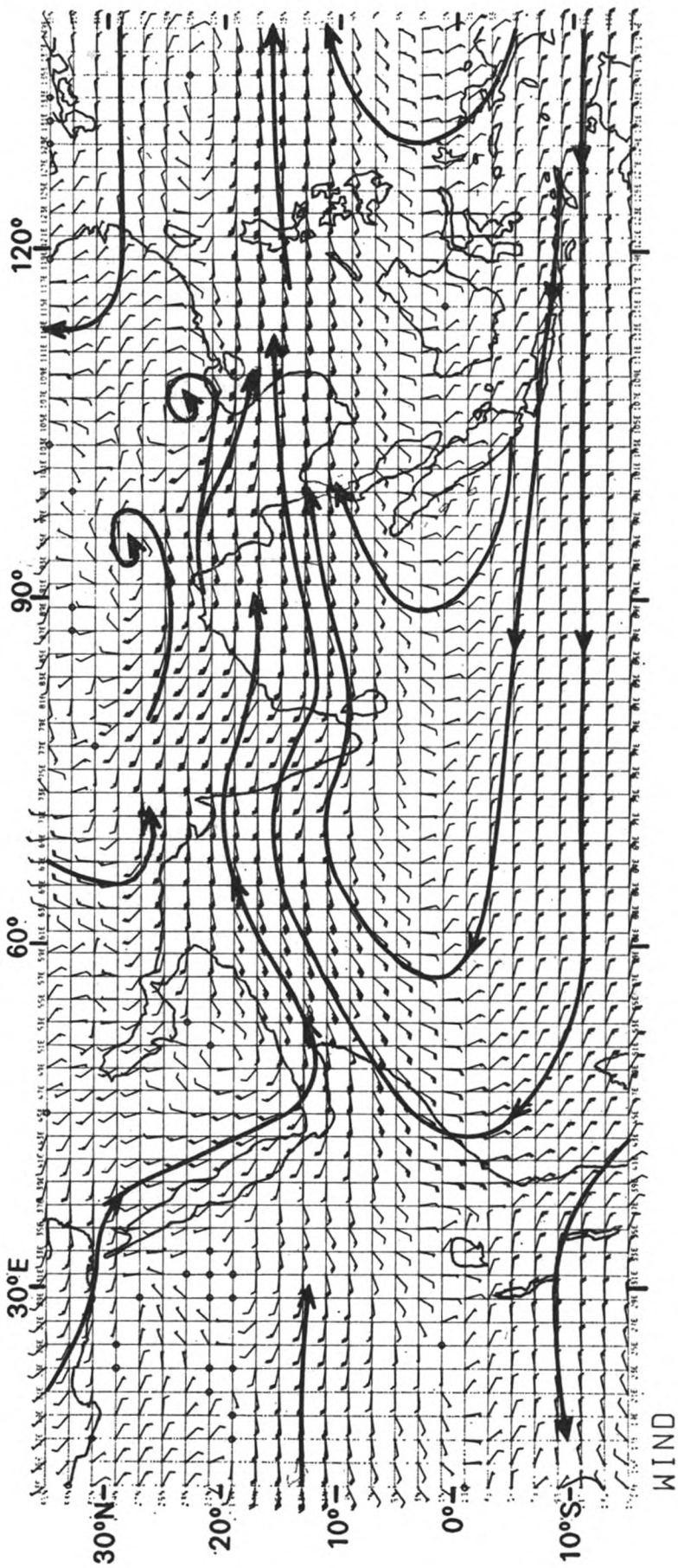


Figure 8—Mean wind flow at approximately 1·5 km as produced by a July simulation of the 11 layer global general circulation model

OTHER WORK OF THE DIRECTORATE OF RESEARCH

Physical Research

Meteorological Research Flight

The Meteorological Research Flight (MRF) of the Meteorological Office is located at the Royal Aircraft Establishment (RAE) Farnborough. It comprises two RAF aircraft, a Hercules C-130 and a Canberra PR3 suitably and extensively instrumented to carry out research from near the sea surface (with the Hercules) to the lower stratosphere (with the Canberra). The flight-deck crews are provided by the Royal Air Force. The MRF is used as a research facility by several research branches inside the Meteorological Office and by universities and other research groups outside the Office, but studies of some atmospheric phenomena are also carried out by scientists based at Farnborough as part of the establishment of the flight.

The value of the Hercules for making observations of wind, temperature and humidity and their fluctuations, particularly in the boundary layer, is now well established and contributions to the JASIN and Ailsa Craig experiments are mentioned elsewhere in this report. Measurements have also been made near Cardington in association with simultaneous boundary-layer observations from the tethered balloon there. Analysis of data from earlier flights has continued and one member of MRF staff spent a year at the National Centre for Atmospheric Research in Boulder, Colorado, working with data collected by MRF and by other aircraft and ships during the GARP Atlantic Tropical Experiment (GATE) in 1974. This work has led to a better understanding of transfer processes in the tropical boundary layer and contributed to the representation of these processes in computer models.

The Office and the Central Electricity Research Laboratories (CERL) are co-operating on a project which is concerned with studing the fate of sulphur dioxide emitted into the atmosphere by power stations. Cloud-water, rain-water, air and particulate samples will be collected on the Hercules aircraft for laboratory analysis, whilst the concentrations of sulphur dioxide, oxides of nitrogen and ozone and the acidity of cloud-water and rain-water will be measured during flight. To facilitate tracking of the relevant power station plume, CERL are developing instruments to detect 'tracer compounds' which will be injected into the plume at source. Manufacture and modification of instruments to meet the requirements of the aircraft environment are being carried out by CERL. Design for the installation of instruments in 1979 is being carried out by the Royal Aircraft Establishment. The project will lead to a better understanding of the atmospheric chemistry of the conversion of sulphur dioxide to sulphate particulates and of the scavenging of both gaseous and particulate sulphur from the atmosphere by direct deposition and by uptake in precipitation.

The Canberra aircraft of the MRF, although restricted to 45 000 ft, is capable of providing accurate measurements of water vapour in the lower stratosphere when the tropopause is sufficiently low. An analysis of data collected over England from 1972 to 1976 showed that the stratosphere was now moister than 20 years ago and that there was also a well-marked annual variation in its absolute humidity. Because of this, our strategy has changed from weekly observations at roughly the same place to intensive observational periods at

3-monthly intervals and covering a latitude range from 45°N to about 70°N. On one of the flights to 70°N a region of the lower stratosphere was found to be warmer and much moister than usual; it contained up to 80 parts per million of water vapour. Subsequent analysis of available synoptic data showed that this observation of a wet (and indeed warm) lower stratosphere accompanied a sharp decrease in the height of the tropopause but the original source of this anomalous moist air is not known.

Since the advent of new data-recording systems in the MRF aircraft, the amount of information gathered per flying hour has increased by several orders of magnitude. In order to cope with the increased data-processing load, a new computer (SEL 32/75) was obtained and delivered to MRF in October.

An extension of the MRF building to include crew-room and briefing area was occupied in September. This has meant that the MRF aircrew and scientific staff can now all be housed in the one building.

Cloud physics

For some years a system for studying the large-scale structure and dynamics of cloud systems by means of 'dropsondes' released from an aircraft has been under development. The Hercules aircraft of the Meteorological Research Flight has been equipped to release the sondes and track them as they fall by parachute and drift with the wind. Sensors on the sondes telemeter data on temperature, humidity and pressure back to the aircraft, which can deal with up to 5 sondes in the air at one time. In 1978 the system was finally cleared for use, after numerous safety checks, and studies of warm-front structure and of the inflow and outflow around convective storms have begun.

On a smaller scale, detailed measurements have been made of the quantities involved in the formation and dissipation of stratocumulus cloud—the drop-size distribution, the solar and infra-red radiation fluxes and the mean and turbulent air motions. Over land, the measurements have been made using the tethered balloon at Cardington and over the sea the Hercules aircraft has been used. Results are being used in conjunction with numerical models to identify the important physical processes and suggest further experiments needed to advance our understanding. Development of instruments to measure drop and particle size and concentrations has continued. After a good deal of development work a holographic device to photograph cloud particles is being installed on the Hercules to complement equipment already in use.

The spatial distributions of air motions and water drops in and around convective cloud have also been studied from the Hercules, to investigate the role played by mixing processes. Some predictions of a 3-dimensional model of vigorous convection have been verified by measurements of the growth-rate of cumulus cloud and the extent of precipitation, in measured environmental conditions. The model is now being used to study electrical effects in thunderstorms.

Cloud data collected in the various experiments can provide important design data for civil and military aviation; the problems of helicopter icing are receiving particular attention at present.

The atmospheric boundary layer

The boundary layer—roughly speaking the lowest kilometre of the atmosphere—is important, not only because it provides the immediate environment

for many human activities, but also because it achieves the transfer of heat, momentum and moisture between the earth's surface and the atmosphere above.

Three major projects have continued during 1978. The first is concerned with the effects of hills on boundary-layer airflow. As reported last year, a 3-dimensional numerical model has been developed to represent these effects and it has now been used to study the flow in stable conditions, with special attention to the boundary conditions at the inflow and outflow of the volume of integration. Several integrations have also been made to see how hills influence the dispersion of pollutants; the results appear to provide a basis for some generalizations.

It was apparent in a preliminary observational program carried out in 1977 of the airflow over Brent Knoll, an isolated hill in Somerset, that a form of rolling motion (Ekman boundary-layer rolls) could be very important, and this has now been studied theoretically, revealing some possible deficiences in current numerical models.

This observational program was extended in an experiment to measure the airflow around the island of Ailsa Craig, off the coast of Ayrshire, which was conducted from 9 October to 13 November 1978. Ailsa Craig was chosen because of its isolation and relatively rounded, smooth shape.

Eleven recording anemographs on 4 m masts were positioned mostly down the eastern slope of the island. Three were vector averaging wind recorders, built specially for the highly turbulent low-speed flow in the lee of the hill where normal anemograph data would be too difficult to analyse. The data from these fixed instruments collected in various wind directions (of the undisturbed air upstream) between north and south-south-east should give an almost complete picture of the surface flow round this nearly symmetrical island. The Cardington probe system was used to measure the turbulence structure of the flow, vertical profiles being obtained by flying the equipment on the tethering cable of a 3000 cubic foot balloon. Unfortunately excessive turbulence in the lee of the hill caused severe downdraughts, making it impossible to fly in the interesting flow structure immediately downstream of the hill. Probe data were therefore obtained aloft only in more 'favourable' wind conditions, and near the surface when the probes were mounted on 4 m masts. In addition the Meteorological Research Flight Hercules aircraft collected considerable data on wind and turbulence round the island and on the extent of its wake.

The second project is concerned with the application of turbulence data collected during various major field experiments to the dispersion of pollutants. Sufficient solutions of the diffusion equation for a passive tracer released from elevated (or ground level) sources have been obtained to understand the sensitivity of the downwind distribution to the basic external parameters: source height, wind speed, surface roughness and sensible heat flux. Some uncertainty remains regarding the effect on the results of the step size (in the integration process), the optimum magnitude of coefficient in the expression for the eddy diffusivity $K(z)$, and in the best form for the lateral spread σ_y.

The third project deals with the Economic Commission for Europe program on the long-range transport of air pollutants which got under way on 1 January 1978. A research program was agreed with the Meteorological Synthesizing Centre (West) in Oslo in April and with the Economic Commission for Europe Working Group in May. Theoretical work has now started on the relation between sulphate concentrations in rain and the sulphur concentration and specific humidity in the air feeding the rain system.

The development of acoustic radars as remote sounding instruments has continued. In particular, experimental work has been carried out to determine whether sounders operating at high frequencies can measure the near-surface heat flux. A project designed to measure the contribution of radiation to the energetics of the boundary layer has been completed. The results indicate that heating due to the direct absorption of incoming solar radiation by the air typically amounts to between 20 and 40 per cent of the total heating of the air. Further data relating to the terms in the energy balance at the air–ground interface, have been collected. It is hoped that these data will make it easier to parametrize the very variable processes occurring at the surface of the earth.

JASIN

The JASIN (Joint Air–Sea Interaction) project is a field experiment to study the interaction of the atmospheric and oceanic boundary layers. Proposed some 10 years ago by the Royal Meteorological Society and the Royal Society and later involving other agencies, including the Institute of Oceanographic Sciences, it finally reached its climax with a two months' phase of intensive observations in the vicinity of Rockall, from ships and aircraft of several nations during the summer of 1978. The objectives of JASIN are (i) to observe and distinguish the physical processes causing mixing in the two boundary layers and relate them to mean properties of the layers, and (ii) to examine and quantify aspects of the momentum and heat budgets in the two boundary layers and the fluxes through and between them. Two field trials were carried out in 1970 and 1972 to develop and test necessary instrumentation. The GARP Atlantic Tropical Experiment (GATE) of 1974 also gave valuable experience.

The Office's contribution to JASIN came from both the Boundary Layer Branch and the Meteorological Research Flight:

(a) *Measurements from ships.* The Meteorological Office unit from Porton provided instruments and automatic recording equipment to measure near-surface pressure, temperature, humidity and wind from 3 ships, HMS *Hecla*, the *John Murray* and the *Gardline Endurer*. A toroidal buoy giving measurements not affected by the presence of a ship, was moored on 14 July and recovered on 1 September, its data being received on the *Hecla* through a VHF link. A total of 163 radiosonde ascents were made from the *Hecla*, measuring vertical profiles of temperature, humidity and wind. On some selected days ascents were made at hourly intervals. A tethered balloon was also flown from the *Hecla*, carrying instruments to measure the turbulent fluxes of heat, momentum and water vapour at heights up to 500 m. One balloon was lost in gales on 22 July but eventually a total of 200 hours of flux data was obtained.

Meteorological Office staff spent a total of 6 weeks on HMS *Hecla*, stationed at 60° 15′N, 10° 30′W. Intercomparisons with other ships were made on four days spaced through the observation period, the most extensive being on 20 August, when HMS *Hecla* was joined by the *John Murray*, the *Gardline Endurer*, the *Meteor* and the *Academician Vernadsky*.

(b) *Aircraft measurements.* The MRF was involved at an early stage in the scientific logistic planning of the experiment and became the international aircraft co-ordinator, responsible for meeting the requirements of other (foreign) participating aircraft scientists and crews. The RAF airfield at Machrihanish was selected as the aircraft operating base, largely because of the accommodation

and facilities available there. As well as the MRF Hercules, the other participating aircraft were a Lockheed Electra (from the USA) and a Mystère Falcon (from West Germany). All three aircraft carried advanced meteorological sensors, and in particular were equipped with gust probes and inertial platforms from which accurate estimates could be obtained of the three components of the wind, and hence, in combination with fast response thermometers and refractometers, fluxes of heat, water vapour and momentum. Other instruments frequently used were a downward-facing narrow-beam IR radiometer for sea surface temperature mapping, and pairs (upward and downward facing) of pyranometers and pyrgeometers for the measurement of radiation flux. All data were recorded on magnetic tape for subsequent processing and analysis.

The operating period for aircraft observations extended from 24 July to 1 September with a break of about a week for aircraft servicing. During this period missions were planned on a daily basis depending on the forecast weather in the operational area. The flight patterns usually selected were either Ls or squares of side 30–50 n.mile, and at a range of heights from 100 ft up to the inversion top or the top of the low cloud and also a temperature/humidity sounding up to 8000 ft. Whenever possible, three heights were flown simultaneously, though the obvious differences in performance between the aircraft restricted this to about 3–4 hours per flight. Frequently, as many as eight patterns were obtained in the boundary layer. Fundamental to the combining of observations from several different platforms, for example aircraft, ships and buoys, is the requirement for frequent intercalibration, and this was included in the flight plans whenever possible. Altogether the Hercules flew about 110 hours on JASIN missions, with similar amounts from the other aircraft. The data are now being processed.

Prevailing weather during JASIN was not typical, being dominated by stationary lows in the first phase and influenced by a blocking high in the second, but it is hoped that the large amount of data collected will yield enough information to fulfill the main aims of JASIN.

The high atmosphere

Successive annual reports since 1972 have recorded progress of the project to develop an infra-red radiometer, known as the Stratospheric Sounding Unit (SSU), to be flown on the US TIROS-N series of operational meteorological satellites and provide routine, world-wide measurements of temperature in the stratosphere. Friday, 13 October 1978 saw an important and exciting step, the successful launch of TIROS-N from the Western Test Range, California (Plate II, left). The SSU was activated on 16 October and immediately produced data of excellent quality. With the flow of this data, the project has entered a new phase.

Effort devoted to software development over the past 2 years enabled us to make immediate use of the instrument data. Our primary task must be to check the instrument, by monitoring the performance of the various sub-systems (e.g. amplitudes and frequencies of the pressure modulators) and the calibration of the radiometer (derived from its response to views of space and an internal target of known temperature) and through measurements of atmospheric emission at locations where the temperature profile is already known (e.g. from a rocketsonde). In parallel with this instrument assessment, the methods of routine production of height analyses from SSU data and of data archiving are being

developed. When data from other instruments on TIROS-N become available and have been assessed, the retrieval scheme will be expanded to include their measurements.

Early results showed that stability of calibration and noise level for 2 of the 3 channels are comfortably within specification and the scan-mirror is functioning well. However, to our great disappointment, the third channel, which was intended to make measurements at around 45 km, is faulty. Although the associated pressure modulator appears to be operating normally, the radiometer output is lower than expected and very noisy. Various possible causes of this problem are being investigated. The fault will have little effect on measurements in the lower stratosphere but will limit the maximum height to which temperature data can be deduced to about 40 km for this spacecraft. An example of an analysis of the 100–2 mb thickness for the northern hemisphere on 20 November based solely on 2 channels of SSU data, is shown in Figure 9.

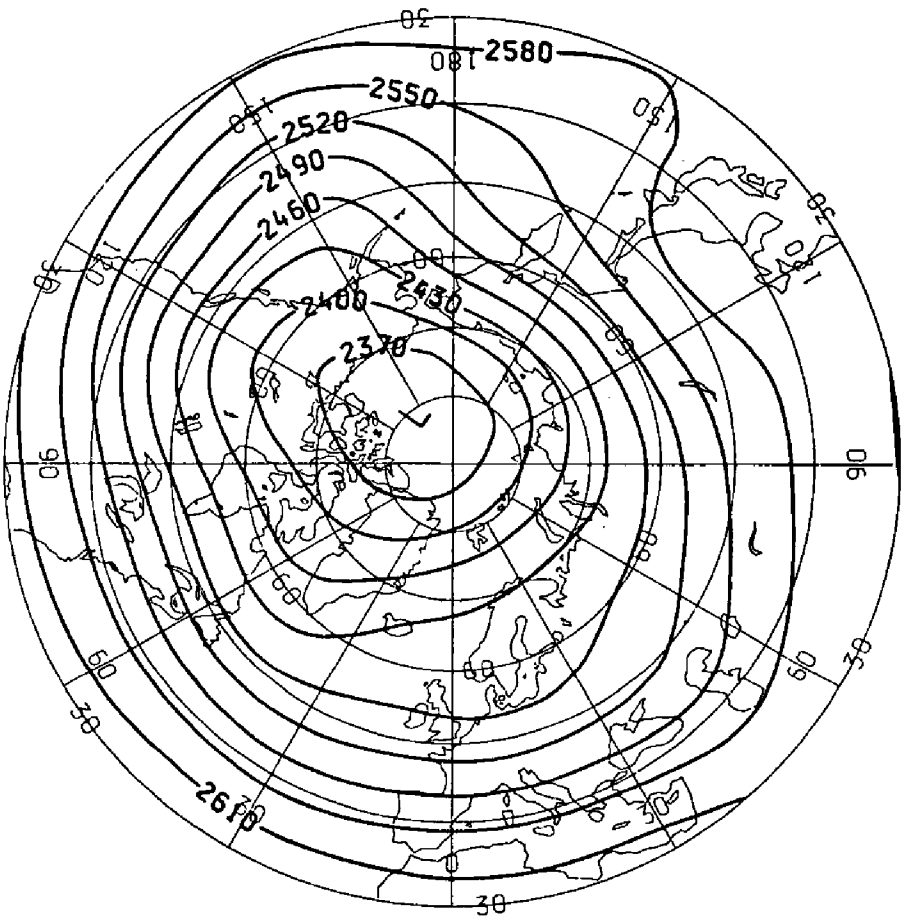


Figure 9—An analysis of the 100 to 2 mb thickness for the northern hemisphere based upon observations from the Stratospheric Sounding Unit at 00 GMT on 20 November 1978

TIROS-N is the first of a series of eight satellites to be launched over the next 6 years. Thus, in addition to the activities in the USA associated with the preparation of the TIROS-N spacecraft, we have also been involved in the test program of the next satellite (NOAA-A) and with other instruments under construction. Marconi Space and Defence Systems Ltd (Frimley) delivered the fifth instrument in July and the remaining three instruments are on schedule for delivery during 1979 and 1980. These require much testing and calibration

before they are operationally acceptable. Laboratory work has included a successful determination of the effect of atmospheric ozone on the weighting functions of the SSU. The result confirmed that the effect is small and can be corrected on the basis of climatological data.

Production of daily northern hemisphere charts at 50, 20 and 10 mb using radiosonde and rocketsonde data has continued. These charts have now begun to be used for comparison with the analyses generated from the satellite radiance data. Programs used to investigate the energetics of the stratosphere as described by objective analysis of conventional data have been adapted for use with analyses of SSU data.

Firings of Skua meteorological rocketsondes from South Uist have been timed to coincide with over-passes by spacecraft carrying infra-red radiometers for temperature sounding in the stratosphere and mesosphere. Direct comparison of the radiances observed by these radiometers and the detailed temperature structure obtained by the rocketsonde are extremely valuable for checking the performance and long-term stability of the satellite instrumentation. Three successful flights were made in January in connection with over-passes of NIMBUS-5 and NIMBUS-6, which carry radiometers developed at Oxford University. The first of a planned series of comparisons with the SSU on TIROS-N was made in November. A modernized version of the electronic package of the rocketsonde has been developed and successfully test-flown as a preliminary to purchasing a new batch of sondes.

Four Petrel rocket payloads, instrumented to measure the vertical distribution of ozone in the height range 40 to 90 km, were completed. An attempt to observe the diurnal variation of ozone was made on 13 September by firing these rockets together with Skua rocketsondes, within a period of 16 hours from South Uist. Unfortunately the experiment was marred by difficulties with the telemetry. The night-time (0147 GMT) flight provided good observations of attenuated ultra-violet moonlight, but weak telemetry signal around apogee may prevent determination of the unattenuated reference level with adequate accuracy. Information on the rocket's trajectory is also somewhat limited. Because of this problem, only one of the remaining Petrel rockets was launched. This provided no information; telemetry ceased at the instant at which the sensors were exposed to sunlight by raising the rocket's nosecone. Investigations of these rocket system failures are being undertaken by the design authorities for Petrel. It now appears probable that the data from the night-time flight will yield an ozone profile with acceptable accuracy. Subject to a satisfactory solution of the rocket system problems, the experiment will be repeated in October 1979, when conditions are again favourable.

Routine observations of total ozone have been maintained at Bracknell, Lerwick, Mahé (Seychelles) and St Helena. The accuracy of these observations and hence their value for assessing possible long-term trends is dependent upon careful calibration of the instruments. The Office participated in an inter-comparison of Dobson spectrophotometers sponsored by WMO and held at Arosa (Switzerland) in August, at which instruments from seven other European countries were adjusted and then standardized against the Bracknell instrument. In this way the various European networks should have been brought into line with the world standard, against which our instrument had been compared at Boulder in 1977.

An instrument to measure nitrogen dioxide by ground-based observations of

the absorption of sunlight at wavelengths around 450 nm is nearing completion and has been installed at Beaufort Park. This gas is of considerable importance in the photochemical reactions which influence the amount of ozone in the stratosphere. The dye laser installation has continued to be used for the monitoring of back-scatter from aerosol in the stratosphere. While emphasis has been placed on gathering observations at the expense of further instrumental development, cloud conditions in combination with technical constraints have made the results disappointing. The amount of aerosol in the stratosphere remains low.

A small balloon radiometer for measuring water vapour in the stratosphere was flown together with a high spectral-resolution instrument on a large balloon in the USA. Most of the effort for this project was provided by the National Physical Laboratory, Teddington.

Satellite sounding of the troposphere

There has been close contact with the European Space Agency (ESA) on many aspects of METEOSAT operations and the Office is assisting in the evaluation of various METEOSAT quantitative products as the techniques to derive them are developed. METEOSAT winds obtained during 3 designated periods were compared with corresponding winds derived from the Central Forecast Office operational height analyses and, for 2 of the 3 periods with co-located conventional wind data. The MRF Hercules aircraft made 2 flights from Gibraltar to obtain temperature, humidity and radiance measurements which were subsequently processed and passed to ESA for use in tuning the programs that produce METEOSAT sea surface temperatures and upper-troposphere humidities.

Techniques and software have been developed to retrieve tropospheric temperatures and surface temperatures from the American-built HIRS-2 (High Resolution Infra-red Radiation Sounder) instrument on TIROS-N. As part of this work a study was made of the accuracy, under varying cloud conditions, of the eigenvector method used by NOAA (US National Oceanographic and Atmospheric Administration) for retrieving atmospheric thicknesses from satellite radiance data. Attention has also been given to microwave tropospheric sounding techniques and data samples from the SCAMS (Scanning Microwave Spectrometer) instrument on NIMBUS-6 have been processed to yield temperature profiles and fields of atmospheric thickness, water vapour, and liquid water content. All were in good agreement with conventional data. Algorithms have been prepared to enable sea surface winds to be deduced from measurements by the scatterometer instrument on the SEASAT-A oceanographic satellite launched in June. Although this satellite failed in October, it is hoped that the analysis of the data which is being undertaken will provide an assessment of the potential operational value of the technique.

Atmospheric chemistry

Efforts to improve the monitoring of the chemical composition of the atmosphere continue. Besides the routine measurement of the chemical composition of rain-water collected at Lerwick, Eskdalemuir and Bracknell (see Plate IV) and the measurement program for atmospheric ozone and nitrous oxide, a gas chromatograph capable of measuring the concentration of several other important trace constituents of the atmosphere is being developed. The chromatograph is being used initially for analysis of air samples obtained on flights of the MRF

aircraft. During a recent detachment to Gibraltar, samples of air from the Saharan dust plume were obtained. These are being used to investigate the possibility that chlorocarbon trace gases are destroyed under the action of ultra-violet solar radiation on the surface of dust particles. This could provide a possible sink for these ubiquitous chemicals which are thought to act as a catalyst in the destruction of stratospheric ozone. An airborne version of the chromatograph is nearing completion. This will give results during flight so that the flight pattern can be modified in the light of the results, if required.

The measurement program is complemented by development of one-dimensional models of the chemical processes which use the more comprehensive descriptions of atmospheric dynamics, developed elsewhere in the Office. Of particular note during the year has been the study of the effect of an increase in atmospheric carbon dioxide on the concentration of ozone in the stratosphere. Results from a coupled radiative-photochemical model have suggested that in contrast to many other of man's activities this could lead to an increase in ozone concentration.

The Short Period Weather Forecasting Pilot Project

The ability to observe clouds and precipitation has been greatly improved by advances in satellite and radar surveillance. These improvements hold considerable promise for improving the accuracy and detail in local forecasts of precipitation for periods of a few hours ahead. The Short Period Weather Forecasting Pilot Project is a 5 to 8 year program to develop these techniques and to optimize their impact on the forecasting capability of the Meteorological Office. The project is intended to be a balanced program of fundamental and applied research into local weather, but before this can proceed it is necessary to establish a network of weather radars and the facilities for handling the data from both radars and satellites.

In 1978 the first of the radars was set up. This is located at Camborne in Cornwall. Since the summer of 1978 data from this radar have been sent by telephone line to the Meteorological Office Radar Research Laboratory at Malvern and also to a local forecast office and a Water Authority in the south-west of England. At present this radar is providing data of a qualitative nature. During the coming year the accuracy of the data will be improved and three further radars will be set up in other parts of the country to form a small network.

Since May 1978 the infra-red data from the European geosynchronous satellite, METEOSAT, have also been available at the Meteorological Office Radar Research Laboratory in a digital format. Both the radar data and satellite data are displayed on colour TV monitors in a matrix of 5 km squares based on the National Grid. Sequences of pictures can be replayed to reveal the movement of weather features. Colours on the display represent rainfall intensity in the case of radar data and cloud top temperatures in the case of METEOSAT data. Both sets of data are received in near-real time and at fairly frequent intervals—15 minutes for the radar and 30 minutes for METEOSAT.

The equipment for the reception and display of a limited sequence of pictures, which has been developed by the Royal Signals and Radar Establishment, is now available commercially. This relatively simple display is for use by some Meteorological Office outstations and by Water Authorities. Work has also begun on a special computer-driven display which will permit the merging of the

radar and satellite data, as well as the fast-action replay of long sequences of these data. The new display system will be used to develop and test methods of forecasting precipitation by objective extrapolation, with additional facilities for man–computer interaction to modify the computer product.

One occurrence which it will be impossible to forecast adequately using simple objective extrapolation methods alone is orographic rain over mountainous areas. Some kind of orographic enhancement correction will need to be applied. Accordingly studies have continued on the nature and mechanism of orographically enhanced rain using radar and other data acquired during earlier field projects in the hilly parts of Wales. Of particular interest is the dependence of the orographic rainfall increment on the low-level wind speed and on the pre-existing rainfall intensity upwind of the hills.

Geophysical fluid dynamics

The high degree of complexity of the atmosphere tends to obscure the fundamental factors that control large-scale atmospheric motions. The main work of the Geophysical Fluid Dynamics Laboratory is intended to explore basic dynamical processes in rotating fluids, of which the atmosphere is but one example. Other natural fluid systems in which rotation plays a dominant role are the atmosphere of other planets, the oceans and the liquid core of the earth where the earth's magnetism originates.

Studies are carried out using a variety of methods, including the detailed examination of motions in rotating fluids in the laboratory, theoretical mathematical investigations and numerical work using high-speed electronic computers. The laboratory systems provide valuable and stringent tests of mathematical theory and suggest new lines of theoretical research. In the laboratory the experimental conditions can be varied over a wide range and theories thereby tested in a manner which is not possible if they are applied only to the atmosphere. We cannot change the rate of rotation of the earth to see if a theory continues to apply, but we can change the rate of rotation of the fluid container in the laboratory. The combination of laboratory experiments and numerical modelling of the same system provides an unique opportunity to subject numerical models to stringent tests which are not possible in other contexts.

Many features of the large-scale atmospheric circulation can be reproduced in liquid filling a rotating annulus, the inner and outer walls of which are maintained at different temperatures. The transfer of heat by the fluid between these walls simulates the transport of heat from the equatorial regions towards the poles by the wind systems. The laboratory studies show that several different regimes are possible. The flow may be axisymmetric, it may contain a 'jet stream' with wave-like perturbations or it may be highly irregular. Experimental and theoretical studies have established the conditions under which such regimes are to be expected.

Laboratory and numerical experiments have been carried out to study the interactions between the different wave modes which develop in these systems. The results indicate that non-linear interactions determine the amplitude of the different waves and the relationships between their phases. Laboratory experiments have been undertaken to enable the effects of large variations in the external parameters (applied temperature gradient and rotation rate) to be assessed while the numerical model has provided detailed energetics for a limited number of cases. Experiments undertaken with a simpler mechanically forced

system have shown that the non-linear interactions are not dependent on the type of laboratory system but are fundamental properties of baroclinic waves. The importance of the non-linear interactions is emphasized by the recent discovery, in the Geophysical Fluids Dynamics Branch, of highly regular 'soliton'-type solutions of a slightly simplified version of the mathematical equations governing large-scale atmospheric motions. If similar solutions are valid in the atmosphere it would imply a higher degree of atmospheric predictability than is suggested by most current theories.

Experiments are being undertaken to investigate the phenomenon of vacillation, the long-period, reproducible, fluctuations in amplitude or shape of baroclinic waves observed both in the laboratory and in the atmosphere. The experiments demonstrate the conditions under which vacillation occurs and detailed velocity measurements indicate that in some circumstances vacillation is accompanied by changes in the energy of the mean flow of the same sign as the changes in the kinetic energy associated with the baroclinic waves. This implies that there are changes in the total energy of the system. Numerical experiments to simulate vacillating flows have so far proved unsuccessful, possibly owing to poor representation, in the model, of the boundary layers, but steps are being undertaken to improve this aspect of the model.

Other experimental work which has been undertaken includes a study of the effects of topographic forcing on baroclinic waves in the mechanically driven system and a study of the structure of the thermocline in rotating fluid subject to heating and cooling at the same level. Apparatus is being constructed to investigate interactions between baroclinic waves and topographically forced waves to understand the role of topographic waves on the transport of heat from the hot to the cold walls of the thermally driven system. Some work has also been done on the related topic of magnetohydrodynamics; a new method has been found for determining the radius of the electrically conducting core of a planet from external magnetic observations. The method exploits the applicability of Alfven's 'frozen field' concept when dealing with changes in the planetary magnetic field over intervals that are much less than the time-scale of ohmic decay. When applied to the earth the method gives for the core a radius which differs insignificantly from the value based on the study of the propagation of seismic waves from earthquakes. The success of the method when tested on terrestrial data makes it possible to design with confidence experiments to determine the sizes of the cores of magnetic planets such as Mercury, Jupiter and Saturn.

Dynamical and Synoptic Research

Research related to numerical short-period forecasting

In recent years there has been a radical change in the way in which meteorological observations are obtained. Formerly, observations of the atmosphere from ground level up to the high stratosphere were made at internationally agreed fixed times (synoptic hours) throughout the world using instrumentation which was, as nearly as possible, standardized and which gave direct measurements of the meteorological variables—temperature, pressure, humidity and wind. The observations at each synoptic hour were put together to give as exact a representation as possible of the instantaneous state of the atmosphere.

Modern technology, however, has led to the deployment of a wide variety of new instrumental techniques to supplement the existing network. The new techniques often differ from the old in that they do not measure the meteorological variables directly, measuring infra-red radiation rather than temperature, for instance. They can give far greater quantities of observations than the old methods by using continuously operating instruments on moving platforms such as satellites or aircraft but only a few of these observations are made close to synoptic hours. The design of analysis and forecasting systems to take full advantage of the wealth and variety of data now available—direct and indirect data, from fixed or moving platforms, received at fixed times or continuously—is one of the challenges of current research work and probably contains the key to future progress.

In one analysis scheme being developed, the analysed value of a meteorological variable is derived in the form of a correction to an existing background field (usually a forecast) which is calculated from a linear combination of the corrections necessary at each observing station (within some sphere of influence) weighted according to the expected accuracy of the observation. Winds and temperatures are analysed simultaneously as three-dimensional fields and may influence one another through simplified dynamical constraints. A further feature is that a knowledge of the statistics of the errors of both the background field and the observations enables the interpolation to be made in a statistically optimal manner, rather than exactly fitting each observation regardless of its reliability.

The introduction of these analysed values directly into a numerical model can upset the balance between physical quantities, and the model forecast may become seriously contaminated by gravity waves as it attempts to adjust towards a more balanced state. To overcome this, the data may be assimilated by repeatedly applying corrections to the background field as it is integrated forward in time, using scaling factors which increase during a period of an hour or so before the observation time and decrease thereafter. This gradually adjusts the background field towards the analysed values in a dynamically consistent way, without excessive generation of gravity-wave noise. The scheme is ideally suited to the assimilation of asynoptic data, since these can be introduced into the assimilation process near their correct time of validity.

A simplified version of such a scheme has been written for the Global Weather Experiment (see page 106) and will be used to produce global analyses every six hours during the special observing periods. An assessment will then be made of the suitability of the technique for use in conjunction with a new operational weather forecasting model to be introduced into everyday use in two or three years time.

The design of the new model is being based on a series of tests using four different hemispheric or near-hemispheric models. The two largest, an 11-level grid-point model and the current 10-level operational model, show comparable overall performance, but on some occasions the forecasts given by them differ significantly. There are a large number of differences between the formulations of the two models and a comprehensive program of tests has been undertaken to determine which features are responsible for the differences in the forecasts. These tests suggest that differences in the initial analysis arising from the interpolation of data are the most likely cause. The two other models in the design test, a 5-level spectral and a 5-level finite-element model, were less

successful but the spectral model has now been enlarged to 11 levels to see if it becomes comparable with the 11-level grid-point model.

These experiments suggest that only small improvements can be made to the quality of the forecast by changing the model formulation and that consequently a future new operational model may be designed primarily on a basis of computational efficiency. This involves combining techniques from several of the models tested. In addition, more fundamental work on the dynamical processes in the atmosphere is being undertaken to try to explain why the forecasts obtained from the best available models are still below the expected standard and do not seem to show substantial improvement with increased resolution or more elaborate formulations.

An alternative approach to improving forecasts is to examine the nature of errors in the immediate past, attempt to predict their distribution in the future and make compensating adjustments to the forecast fields. At the 500 mb level it has been found that part of the 12-hour forecast errors can be represented reasonably well by low-order autoregressive moving-average models. Over wide areas of the hemisphere up to 50 per cent of the forecast error may be accounted for in this way. The study is being extended to other levels with the object of using a scheme of this sort to reduce the magnitude of forecast errors on an operational basis.

A major preoccupation during the year has been the improvement of methods of short-range quantitative prediction of rainfall over the British Isles. Following the encouraging results of a preliminary study using a diagnostic scheme with a $3\frac{1}{3}$ km mesh for enhancing the forecast rainfall in mountainous regions, extensive daily evaluation tests are being conducted. For some purposes the fine spatial detail of orographic rainfall is not required and it is sufficient to provide forecasts of average values over 100 km grid squares. Tests are being carried out on a simpler model which represents the orography statistically within each large grid square. The results appear to be comparable in accuracy with averaged values obtained from the $3\frac{1}{3}$ km grid model.

Another problem that has been investigated is the underestimation of rainfall during the first six hours of the operational forecasts. A method of improving this, which involves more elaborate cloud physics, has been successfully tested. A useful by-product of the scheme is that it permits a more direct prediction of cloud amount. The structure and evolution of fronts and their relationship to the synoptic-scale flow is a fundamental aspect of rainfall production. Work is going ahead on investigating both idealized baroclinic waves and real situations, using a model whose vertical and horizontal resolution may be varied. Experience so far suggests that an improvement would result if the grid length of the operational model were reduced to 50 km, but it is not clear if additional gains would be made by further reduction.

The possibility of using a limited-area ultra-fine-mesh mesoscale model for short-range forecasting is being studied. So far, the experimental mesoscale forecasts have been based on information obtained from a synoptic-scale model. Time-dependent boundary conditions have also been interpolated from the synoptic-scale forecasts. This approach works well for the only case study that has been completed, and can be expected in many situations to give good indication of the general character of local variations in the weather 24 hours in advance. However, good short-range forecasts require initial conditions that are detailed and accurate, and work has begun on determining which observa-

tions are most likely to improve the forecasts and how best to use the information that is available. The performance of the model in simple and extreme situations is being tested.

General circulation

The long-term research program to study the general circulation of the atmosphere with the aid of numerical models has continued. Two basic models are used, with 5 and 11 levels in the vertical respectively and corresponding differences in horizontal grid length, the coarser version being used when longer-period integrations are necessary.

A distinction may be drawn between those atmospheric processes which occur on sufficiently large space scales to be handled explicitly in models and those where the associated dynamical systems are too small to be so treated, and whose space-averaged effects have therefore to be estimated on a mainly physical but also partly statistical basis in terms of variables whose values are known only at grid points. The latter processes include the interactions between the atmosphere and radiation, solar and terrestrial, and between the atmosphere and the earth's surface. By their nature, they cannot be estimated precisely from grid-point values and it is a continuing research task to improve the methods of incorporating them in general circulation models.

The transfer of radiation through a clear atmosphere is fairly well understood, and the most urgent problems that remain in calculating radiative fluxes concern the interaction with clouds or suspended dry particles. The effects of clouds are particularly important, as they cover on average about one-third of the earth's surface and they both prevent solar radiation from reaching the surface of the earth and trap terrestrial radiation which would otherwise escape to space. It is very difficult to calculate the detailed distribution of clouds from the large-scale variables available in general circulation models, yet the radiative exchanges can be quite sensitive to details of the distribution. Most models used until now have avoided the difficulty by prescribing the cloud distribution on the basis of climatology or in some other way which does not depend on the variables in the model. This is clearly unsatisfactory when possible changes in climate are being modelled, because the effects of any consequent changes in cloud are one of the things that must be included in the modelling. During the year a new procedure for calculating radiative transfers which included a specification of cloud type and amount dependent on the model variables was extensively tested in integrations for tropical regions (see the Special Topic article) with encouraging results. Additional problems arise when the scheme is applied globally as a larger range of possible cloud mechanisms has to be considered. Investigations are now proceeding to produce a scheme that will be as successful everywhere as it has already been for the tropics.

The sensitivity of model simulations to the method of calculating the exchanges of heat, water vapour and momentum at the earth's surface has been the subject of continuing investigations. These have involved the use of single-column representations of the atmosphere to study the effect of varying the albedo, ground roughness and soil thermal capacity as well as 2- and 3-dimensional models in which the wider climatic effects are revealed. Ways of achieving realistic vertical structures in the atmospheric boundary layer, through which the physical quantities exchanged at the surface are transferred into the free

atmosphere have also been studied. An assessment of the optimum number of layers (taking account both of physical realism and computational penalties) to include within the boundary layer in a general circulation model so far indicates that the choice made for the 11-layer model (that is 3 layers) should be adequate for most purposes. A scheme for the 11-layer model which allows the height of the boundary-layer top to vary continuously has been developed. Problems which occur when the layer is stable and there is a tendency for a new boundary-layer to form close to the earth's surface are being studied.

The influence on climate of factors that are external to the atmosphere itself is one of the most important areas in which general circulation models are used. Most models assume a representation of the earth's orography obtained by averaging mountain heights over an area surrounding each grid point. This may well give an underestimate of the effect of mountains on the atmosphere, particularly for high narrow ridges where the tendency to block the airflow is almost certainly important. Computations were carried out in which mountain heights in the model were increased so that the barrier effect was more adequately represented. The resulting changes in the general circulation were substantial, some features being more realistic, others less so. The results are being studied in order to try to decide the best way of representing mountains in the models.

More experiments have been carried out to increase our understanding of how anomalous sea surface temperatures influence the atmosphere. It has previously been shown that the largest effects in middle latitudes are produced, not by anomalies in the same latitudes, but by unusually warm or cold water in tropical or subtropical regions. The later experiments, which considered specific observed anomalies, have had the main purpose of quantifying the effect in relation to the extent and intensity of the anomalies and in relation to the size of other influences on the atmosphere. The time-scale on which the anomalies affect the atmosphere has also been investigated.

Taking all the integrations performed with a model for a given set of external conditions, such as sea surface temperatures and radiation parameters, it is possible to build up a picture of the model's climatology. Particular aspects of the simulated climatologies have been studied during the year. Thus, the structure and behaviour of the longest atmospheric waves have been analysed and compared with those of the atmosphere. This investigation was prompted by several recent scientific papers in which it has been shown that in simplified linear models the conditions imposed at the upper boundary substantially affect the representation of these particular features. The possibility that conditions very high in the atmosphere could have a large influence on the long waves in the troposphere has been taken up by some scientists as a mechanism by which solar effects or small changes in the stratosphere could affect climate at the earth's surface. The question whether the long waves in more complete models, and, by extension, in the atmosphere also, are similarly affected has therefore assumed increased significance. Analysis to date does not appear to confirm the suggestion that waves in the troposphere are very sensitive to conditions in the high atmosphere. The investigations show that the models have considerable skill in handling the longest waves, both in forecasting them from real atmospheric situations and in simulating them climatologically. There are differences between the waves in the atmosphere and as simulated by the models, but as there are many factors involved, the forcing by conditions at the earth's surface being particularly important, the extent to which they are systematic and

caused by the boundary conditions imposed at the top of the atmosphere remains unclear.

During the last several years considerable attention was given to the development of schemes to represent the effects of small-scale convection in general circulation models. The introduction of a scheme which deals more effectively with the transfers of heat and moisture in deep convection (as discussed in the Special Topic article) led to improvements in forecasts for areas of the tropics, particularly as regards the computed rainfall amounts. The scheme has been used in global climate simulations and the rainfall computed over the globe has been systematically compared with climatological estimates. On the whole, the rainfall simulations have been improved in comparison with previous computations, though it has been noted that there is a tendency for substantial rainfall to encroach into marginal desert regions and the tropical values are rather higher than climatological estimates. However, in view of the uncertainty in the latter, it is not obvious what weight should be given to this feature of the results.

Results from our general circulation model were used by a distinguished visiting scientist, Dr G. B. Tucker, Chief of the Atmospheric Physics Division, Commonwealth Scientific and Industrial Research Organization, Australia, who spent some weeks in the Office studying the computed large-scale eddy fluxes of heat and momentum.

Climate modelling

General circulation models provide a powerful tool for the study of climate. Significant advances into what is clearly going to constitute a long-term research project have been made in 1978. The most recent version of the 5-level model has been used to simulate a complete global annual cycle. This integration which was carried on to 450 days required over 100 hours of computer time on the IBM 360/195 and has produced a great deal of data for analysis. An initial survey indicates that the model has produced a realistic simulation of the evolution of the annual cycle, though some deficiencies are noted. One important result observed is that the computed annual variation of radiative heat flux at the top of the model atmosphere agrees well with values from satellite observations.

The measured increase in atmospheric carbon dioxide content and estimates of its concentration into the next century have provoked much discussion about possible future climate perturbation arising from the 'greenhouse' type of effect it is known to produce. As a first stage in a numerical study of such effects, the annual integration described above has been repeated for an atmosphere in which the CO_2 content was doubled. A preliminary study of the results indicates that in the winter the model response to the effect of increased CO_2 was difficult to separate from the natural variation expected between two model runs, while in the summer hemisphere a mean increase of surface temperature of less than 1 °C and a 5 per cent reduction in rainfall over the oceans were noted. These results should be considered as first estimates only, an important proviso being that the sea surface temperatures were assumed to retain their present climatological values.

It is evident that a numerical model incorporating the interactive effect of ocean and atmosphere is essential to study climate change. Some work has proceeded in this direction, firstly by studying the response of atmosphere and ocean using a single-column model applied at an individual point, and by

attempting an integration of a general circulation model incorporating an interactive oceanic mixed layer. Results from the latter have indicated particular places and circumstances in which there are errors caused by the assumptions about the ocean. Investigations are proceeding on methods to overcome these problems, while retaining the essential simplicity of the oceanic representation. Study of the dynamical interaction between the atmosphere and oceans is expected to be a major preoccupation during the next decade or so.

Global Weather Experiment

Preparations have been made during the year for a major investigation during 1979 in connection with the First GARP Global Experiment (FGGE). During the whole period of the FGGE (December 1978 until the end of December 1979) but particularly during the two Special Observing Periods 5 January–5 March 1979, and 1 May–30 June 1979) an enhanced network of observations will be available over the globe. The aim of the Meteorological Office experiment will be to use the observations for three purposes: (i) to investigate objective analysis schemes that are specially suitable for dealing with the mixture of observing systems—satellites, aircraft, floating balloons, floating buoys etc. that will be deployed, as it seems likely that the routine global observing system will become in time a similar mixture, (ii) to investigate the importance of particular elements of the system such as satellite temperature measurements or observations of surface pressure over the southern oceans to the analyses that are used by the Meteorological Office and (iii) to study how forecasts for the British Isles depend on atmospheric developments elsewhere, for example in the tropics and in the southern hemisphere. During the two Special Observing Periods, it is proposed to run a near-real-time continuous forecast–analysis cycle, in which a forecast for 6 hours ahead becomes the background for an analysis based on the latest observations. The analyses will provide the basis for later investigations to study the specific topics outlined above. A global version of the 11-layer general circulation model will be used. Observations covering the entire globe received at Bracknell by normal telecommunication channels will be assimilated directly into the model. They will include the special observations, some of which refer to non-standard times, planned for the FGGE. All the necessary programs and procedures have now been prepared and a trial run carried out in October 1978 gave very encouraging results.

Research related to long-range forecasting

Forecasts for 30 days ahead continue to be issued at the beginning and midpoint of each month. Each forecast contains information on the general character of the weather to be expected over the United Kingdom and the associated average temperature and rainfall. The format was the same as in previous years; for each of 10 districts of the country temperature is specified in terms of 5 categories (quintiles) and rainfall in terms of 3 categories (terciles), each of which, based on data for the 30 years 1941–70, is equally likely. In addition, a general indication is given of the likely incidence of frost, fog, snow, gales and thunderstorms, depending on the time of year. Subscribers to the full published version of the forecast receive a document entitled *Monthly weather survey and prospects* which provides, in addition to the statement of the forecast, climatological information relevant to the time of year and information on weather of the previous month.

The consultancy service introduced in 1977 has attracted a few subscribers and has also led to discussions with commercial customers regarding the best format and overall content of each forecast. As a result forecasts have been produced experimentally in terms of the probability of each temperature quintile and extended geographically to provide temperature and rainfall indications for much of the continent of Europe. Some of the forecasting methods are capable of application to any station or group of stations for which long-period records are available, and have been applied to 18 representative stations within Europe.

Seasonal statistics which present indications about the coming season based on historical data were compiled and issued to subscribers who required them. This document comprises lists of projections of temperature and rainfall over Britain for the forthcoming three-month season provided by a variety of objective statistical methods, with, if possible, an indication as to the reliability of the methods for that particular season. Commercial subscribers to this and other long-range forecast services cover a wide range of activities and interests including civil engineers and companies trading in products whose production, distribution or consumption is weather-sensitive.

The long-range forecasts are still derived mostly from statistical considerations. By comparing what happened in the past with the current development of the atmosphere, a forecaster tries to deduce the most likely evolution of the atmospheric flow during the ensuing month (or season). The data employed relate mainly to pressure and temperature, with upper-air data playing an important part for the period from 1947. Computer-based methods of numerical analysis have proved particularly valuable in the reduction of the massive quantities of data involved. Nevertheless no objective system is, as yet, capable of reproducing the skill of experienced meteorologists in assessing the available evidence, and human judgement continues to play an important part in formulating the monthly forecasts.

The year 1978, like 1977, has proved a particularly difficult year for long-range forecasting. This is partly because the short data-base (approximately 100 years) has not included sufficient good analogues to support statistical techniques, and partly because circulation patterns near the British Isles have been more meridional than in any earlier period of production of long-range forecasts, so that small displacements of the main weather systems or relatively minor changes of wind direction have involved large variations of temperature and rainfall. This characteristic of the circulation is highlighted by the score which would have been achieved if forecasts had been based on persistence, that is by predicting temperatures in the same quintile as in the previous 30 days. Persistence showed the lowest skill since forecasts were first issued in 1964 while the forecasts which were issued, though achieving a rather dispapointing result, showed the greatest improvement over persistence since that date.

Further development has taken place during the year of the numerically based methods used to extract information relevant to each forecast. Investigations using principal component analysis (eigenvectors) have been extended by processing 60 years of half-monthly mean surface pressure data for a grid covering most of the northern hemisphere. The principal component coefficients are being used to forecast half-monthly fields of pressure in the vicinity of the British Isles. There are indications that these methods may be capable of contributing a small but useful improvement in forecasting skill in

the future. In addition, enhancement of the Meteorological Office computer system (COSMOS) has enabled the large amounts of data involved to be processed more speedily. It is now possible to work towards improving efficiency by merging procedures common to more than one forecasting method and reprogramming other sections to take advantage of the new facilities. An integrated operational forecasting suite is being developed which will provide for greater speed, flexibility and efficiency and will improve the presentation of material for subsequent assessment of forecasting methods.

The data base itself, comprising monthly mean values of meteorological quantities for all parts of the world, has been substantially improved during the year, with important acquisitions from the United States National Oceanic and Atmospheric Administration (NOAA) and the Deutscher Wetterdienst. In addition to the standard parameters such as pressure and 500 mb height there are now available monthly mean values for all parts of the globe of incoming solar and outgoing long-wave radiation measured from polar orbiting satellites during the period from June 1974 to date. It is intended to apply these data to study the influence of cloudiness, albedo and sea surface temperature in the tropics on subsequent weather development in higher latitudes.

All data sets are kept up to date on a current basis and the data are archived on magnetic tape as they are received. In addition the archive of charts of monthly mean values of surface and upper-air data is kept up to date, the charts being prepared and analysed in the 'Climat Laboratory'. Corresponding charts for the southern hemisphere are received from Melbourne.

Work has continued also on the homogenization and quality control of the various data sets held. Considerable work was necessary to achieve compatibility of data from different sources, and periods of overlap between data sets have been useful in identifying and removing inconsistencies. Among the more difficult problems to resolve has been the different methods of interpolation used to derive grid-point data in areas where observations are few. In respect of sea surface temperature data it has been necessary to develop new methods of quality control to achieve both geographical and chronological consistency especially in situations where there are large variations in the density of observations. The effects of gradual changes in the methods of measurement have also had to be explored.

There has been a substantial increase not only in the amount of data exchanged with other meteorological services but also in requests for data from other national meteorological services and research institutions. Sea surface temperature data for the North Atlantic and grid-point upper-air data have been in particular demand.

Statistical studies of large-scale circulation

The study of weather sequences through the 27-month cycle of the Quasi-Biennial Oscillation (QBO), a reversal of wind direction in the equatorial stratosphere which occurs every two years or so, was extended to the whole of the northern hemisphere. Charts for the period from 1954 to date for monthly means of surface pressure, lower troposphere mean temperature, and 500 mb geopotential were analysed so as to display any regular variations with a period in the range 22–36 months. Some correspondence was found between features of the airflow over the northern hemisphere and the phase of the QBO. For instance the mean position of the jet stream was further north in the westerly

phase than in the easterly phase of the QBO. However, the apparent relationships between the flow and the phases of the QBO appear to vary substantially with longitude and from cycle to cycle. The variations are being followed in respect of the current weather and an experiment is being conducted to test the usefulness of the observed historical QBO relationship with the flow in temperate latitudes to long-range forecasting. The evolution of northern-hemisphere flow patterns during the 10 QBO cycles since 1954, when direct observations began, is also being used to provide estimates of the behaviour of earlier QBO cycles.

Work has continued on the compilation of a comprehensive catalogue of indices which, using all the information available from instrumental records and historical weather charts, describe for each day, pentad or month, the main aspects of the weather over the United Kingdom, Europe and the North Atlantic for the whole period for which records are available. The work on gale indices for the United Kingdom and North Sea areas was completed for the period from 1881 to date.

A project is under way to extend a set of daily indices of flow and vorticity over the United Kingdom and North Sea back over the past 300 years. Initially monthly indices will be produced using relations established between the indices and regional temperature and rainfall together with limited wind and pressure data. Monthly and annual rainfall series have been produced for Ireland (1711–1880), Scotland (1757–1869), and England and Wales (1669–1726) to add to existing later series. Pilot studies have been made of the relationship between flow patterns in the Atlantic–European area and limited pressure, wind, temperature and rainfall data. Daily catalogues have been compiled of central England temperature from 1814 to date, and of daily rainfall from 1871 in each of four regions of England and Wales (north-west, south-west, south-east and north-east). These will provide, in conjunction with the daily flow and vorticity indices for the United Kingdom from 1881, a valuable quick reference to the weather on any day.

Ninety-six years of pentad (5-day) mean values of flow and vorticity indices for the Atlantic–European area, expressed as standardized differences from their mean value, have been assembled. For each year (September to August) the data have been analysed spectrally. It appears that, in any particular year, it is often possible to select a characteristic wavelength which accounts for a significant part of the variability. The most common wavelengths were around 45, 65, 100 and 200 days. These were found for each of the indices, and were also prominent when the data were grouped in 2-year, 4-year and 8-year sets. Possible applications of these results are being studied.

Work has continued on the study of the dynamics of blocking, and in particular on the changes that occur when the predominantly westerly mid-tropospheric winds over and around the British Isles are replaced by a blocked or meridional flow pattern. There is evidence that prior to blocking, the mean zonal flow at 500 mb over the northern hemisphere is displaced northwards, and coherent changes in the positions of the long wave troughs and ridges around the hemisphere can be detected up to about 20 days before the onset of the winter half-year. The changes are complex but it is hoped that the study will provide a basis for useful guidance for forecasting the onset of a blocking pattern and the associated substantial change in weather type. Experimental forecasts are being made on current weather data.

Climatic change

Amid continuing speculation concerning the possibility that recent abnormal conditions were indicative of a persistent change of climate, work continued on establishing a better data base to determine exactly what has happened over the globe over the period for which instrumental records are available and then analysing the data for evidence of any long-term trends. The difficulty of constructing an accurate picture of past conditions on a global scale is illustrated by the fact that monthly mean charts of 500 mb height produced by different nations show differences over the oceans of up to 10 decametres (corresponding to temperature differences of 5 K). Studies are being made of the causes of these and other similar differences in an attempt to establish the most reliable climatic values and make good estimates of their possible errors.

Over Britain itself the data are, of course, more plentiful and reliable. The recent incidence of blizzards, warm, cold, dry and wet spells has been studied in relation to long-term records. There is no reason to believe that the incidence in recent decades has been greater than would be expected on the basis of these records. Further studies have been made of the connections between long-term changes in temperature (both in Britain and in the northern hemisphere as a whole) and the patterns of circulation over the North Atlantic; various plausible hypotheses have been disproved but few positive results have emerged.

Application of dynamical methods to long-range forecasting

The possibility of using general circulation models to help in forecasting for periods of up to a month ahead continues to be explored. Integrations have been carried out from real atmospheric conditions, and imposing either climatological sea surface temperatures or actual sea surface temperatures as observed at the initial time. One aim has been to determine the relative influence the state of the atmosphere and forcing by surface anomalies have on developments in the atmosphere over periods of a month or so. As expected, the 'memory' of the state from which an integration starts diminishes with time, but there is a need, in general, to take it into account in forecasting for periods of a month ahead. Widespread sea surface temperature anomalies of a degree or two have been shown to be highly significant in climatological-type integrations, when their effect on the atmosphere has reached its asymptotic value. When dealing with forecasts of 30 days or so, their importance is more difficult to demonstrate partly because it must be supposed that their influence has already been absorbed into the atmospheric state, and because their direct effect on the atmosphere builds up only slowly. At 30 days, the differences that can be directly attributed to typical differences in sea surface temperatures are in general less than those due to typical differences in initial atmospheric conditions.

If the general circulation model is to be used in long-range forecasting we must have practical experience of its behaviour with different starting conditions and at different times of the year. The model has therefore been run to 50 days once or twice a month, using real initial data. The results are being analysed quantitatively and a start has been made on producing a detailed and consistent climatology of the model.

In view of the widespread concern about the causes of the cold weather in July and early August the model was used to study the possibility that excess ice

in Hudson Bay was a contributory factor to the persistence of a downstream trough in the upper-air flow near western Europe. The results indicated that while a cold Hudson Bay might have been a minor contributory factor it was probably not the major cause, and was probably not as important as anomalies in sea surface temperature over oceans in lower latitudes.

Stratospheric research

Studies of stratospheric dynamics have concentrated on the 'sudden warming' phenomenon. Two lines of research have been pursued—analysis of a warming produced during previous integrations of a 13-level model of the troposphere and stratosphere, and a study of the dynamics of the major warming that was observed during the northern-hemisphere winter of 1976–77. As a result of these studies a better understanding of the mechanism of the phenomenon is being achieved. It appears that earlier theories are in need of extension—meridional transport of momentum associated with planetary wave motions has been identified as playing a fundamental role.

The major effort in stratospheric research has, however, continued to be in the field of chemistry, particularly the study of possible ozone perturbation arising from artificial injection of chlorofluorocarbons (CFCs). The transport of these species has been studied using a two-dimensional model in very-long-period integrations. A simpler three-column model, these columns intended to represent tropical, middle and polar latitudes has been used in conjunction with a detailed chemistry scheme to provide estimates of ozone perturbation. It is felt that these models, though themselves gross simplifications of the real atmosphere, provide more realistic simulations than can be obtained with the one-dimensional (that is globally averaged) versions which many researchers have used for these studies. Integrations have been made assuming different scenarios regarding the future release of CFCs. The work is now almost complete and results have been reported, initially to the Department of the Environment on whose behalf the research was undertaken. The results indicate that these species will have an atmospheric lifetime of 50–100 years and if their emission were to continue indefinitely at the current rate, an equilibrium ozone reduction of 10 per cent would be achieved. The computations produce also details of the geographical and seasonal distribution of the ozone changes. It is very apparent that many assumptions and approximations have to be made and uncertainties whose overall effect is hard to quantify exist in all aspects of the subject. In particular, the results would be substantially affected if a mechanism for removing CFCs from the troposphere were identified.

Special investigations

The Special Investigations Branch is engaged in applied research and in answering meteorological enquiries. The distinction between these is largely one of time-scale: both require investigations in response to operational problems most of which arise in connection with aviation, though an increasing number concern non-aviation matters; both involve the exercise of scientific judgement in appraising indications from data that are often inadequate.

There has been an increased demand, mainly from aviation, for climatological data. This apparently straightforward task often requires considerable

computing expertise to extract and present the data in the form required. Aeronautical climatological summaries for about 250 stations world-wide have recently been prepared in microfiche form for British Airways.

The principal research emphasis for aircraft operations continues to be on the effect of low-level wind variations on take-off and landings. The results of 'wind-shear' forecasting trials carried out last year at a number of airports have been positive enough to lead representatives of British Airways to recommend that wind-shear forecasting be introduced on an operational basis.

Concern has been expressed by pilots that wind information passed by air traffic control just before landing or take-off is often based on a central anemometer whose measurements may be unrepresentative of conditions experienced by the aircraft which can be up to 3 km away. A Working Group set up by the Civil Aviation Authority to consider the need to mount anemometers near take-off and touchdown points has recommended that recording units should be attached to the two Heathrow anemometers to measure the spatial wind differences. This recommendation is about to be implemented. A study of the frequency and nature of wind squalls which can cause substantial wind differences over a small distance is also being made at Heathrow.

In recent years, increasing operational pressure to fly helicopters in supercooled cloud and heavy snow has led on the one hand to a demand for the development of adequate icing protection systems, and on the other for an improved knowledge of the probability of encountering severe icing or heavy snow conditions, particularly in northern latitudes in winter. The Office was represented on a Working Group set up to draft a co-ordinated research and development plan which has now been approved by Service Chiefs of Staff. The Office's contribution will consist of an atmospheric-data-collection program linked to a climatological and forecasting study and this has now begun. Scientists concerned with both aspects of the project have established active collaboration with helicopter engineers who are developing protective systems.

Airlines are still concerned with clear-air turbulence which may cause passenger discomfort and even physical injury. A large number of pilots' reports collected during a specified period in 1976 have been analysed. Multiple regression techniques are being used to identify the relevant parameters that can be used in an objective probability forecasting scheme and determined automatically from the operational numerical forecast model.

The Office has a representative on the CAA Civil Aircraft Airworthiness Data Recording Program Working Panel which examines the outputs from flight-data recorders fitted to about 40 aircraft to search for 'events' in which abnormal flight behaviour occurred. Study of these 'events' may result in the identification of potential causes of accidents. Recently, the Office representative made a meteorological analysis of a take-off incident at Heathrow in a strong cross-wind in which a severe roll near lift-off resulted in one wing-tip nearly hitting the ground. Another investigation concerned the anomalously high frequency of hard landings reported at an airfield in the Near East. In this case, meteorological factors were discounted.

A small team helps and encourages investigations carried out at outstations mainly in relation to the forecasting of local weather. Computer services for the provision of data and various forms of analysis as well as guidance are supplied. This team also provides lectures and a computer service for students' projects at the Meteorological Office College and helps in the assessment of their

projects. Last year, two outstations' investigations led to significant progress in developing probability forecasts for local fog formation and dispersal, and one paper describing some interesting features associated with a katabatic flow observed at a station in Germany was discussed by the Meteorological Research Committee.

The volume of enquiries concerned with pollution has maintained a high level. These are mainly concerned with advice to firms in the chemical industry, in forecasting the spread of chimney plumes and in planning emergency action in the event of a serious leakage of dangerous contaminant. Improved mathematical models of factory plumes have been developed.

Radio-meteorological enquiries continue at a significant level, and are principally concerned with the effects of precipitation and of evaporation ducts on microwave communication links. In relation to this there is an increasing demand for rainfall statistics in sea areas. There is also an increasing demand for cloud statistics in various forms from diverse sources. For this purpose daily meteorological reconnaissance flights from several UK stations during the 1940s and 1950s contain a unique source of cloud data, and plans are in hand to put these data in machinable form.

Several investigations in the Branch have been concerned with providing forecast data in the form best suited to the needs of particular users—often in the form of quantitative statements about the probability of specific weather conditions. Important examples are studies of the relationship between meteorological variables and the daily 'sendout' of the gas industry and of a more quantitative basis for the 'dry spell' forecasting service used mainly by farmers. Work has also continued to produce and improve formulae for the prediction of storm surges at various coastal stations. This concerned particularly the Kings Lynn floods and the construction of the Humber barrage. Requirements for data to produce predictions of 'negative storm surges' in connection with the possible grounding of oil tankers are also handled.

General Activities of the Research Directorate

The Meteorological Office continued to work closely with a number of national and international bodies which are concerned with meteorological research. The Office provides representatives on a number of research-oriented committees of the Royal Society, the Natural Environment Research Council and the Science Research Council. In the international field, scientists from the Office serve on several working groups of the World Meteorological Organization and of the International Association of Meteorology and Atmospheric Physics.

The scientific research of the Office was reviewed by the Meteorological Research Committee and its subcommittees during the course of nine meetings. The Committee also advises on a number of small university research projects which are directly supported by the Meteorological Office; these number five in addition to four placed through the Gassiot Committee of the Royal Society.

During the year several members of university staffs worked in the Office as consultants for short periods; three scientists from overseas worked for longer periods, during which they were supported by their home institutions, including a scientist from China who completed a one year's stay for the study of problems of urban airborne pollution.

Library, Editing, Publications, Archives and Cartographic Section

The National Meteorological Library forms part of the Meteorological Office Headquarters at Bracknell. It is used mainly by the staff of the Office but there is also a large demand for its services from universities, schools, commercial and industrial firms and the general public.

The first stage of the Meteorological Office Library Accessions and Retrieval System (MOLARS) was introduced as planned at the beginning of the year and after a few minor problems has operated very satisfactorily. MOLARS is based on a dedicated mini-computer that can be linked with the Meteorological Office mainframe computer complex COSMOS. A single input of the bibliographic details into the system via a Visual Display Unit results in the printing out of all the various special formats, which may be as many as ten, required for author catalogue cards, subject bibliography sheets and the *Monthly Accessions List*. The last item is now available before the end of the month following that to which it refers, an improvement of some three or four weeks. The accessions phase having proved successful, financial approval was obtained for the second (retrieval) stage; when the extra equipment and programs are available it will be possible to interrogate, on line, the data base which has been built up over the last seven years and contains all the accessions for that period.

While the number of items classified and catalogued (which includes all relevant journal articles) was similar to that of 1977, the number of loans was up by 13 per cent, the April total of 2324 being the highest monthly total recorded.

In the Visual Aids section, considerable efforts have been made to expand and update the collections of slides and photographs and loans of these items have increased by some 20 per cent. Videotape recordings of relevant television programs are also held in this section.

Co-operation with other libraries particularly those of other Government departments has continued to be strengthened. The access to on-line bibliographic data bases available through some of these contacts has proved most useful especially in peripheral fields. We were pleased to welcome visitors from Hong Kong and the Caribbean Meteorological Institute for training courses in meteorological librarianship.

The Editing section remained responsible for preparing for printing most of the official publications of the Office, and co-operated closely with Her Majesty's Stationery Office in the maintenance of publishing standards.

Works published during the year are listed in Appendix III; they include the *Meteorological Magazine*, a monthly journal containing short scientific articles, reviews, and items of interest to meteorologists everywhere.

The distribution of publications, both official and commercial (scientific journals, textbooks, works of reference etc.) to the Office's many outstations is under the control of the Publications section, which is also responsible for the half-yearly issue of some 350 000 observation forms of all kinds to over 6000 reporting stations.

Meteorological observations in manuscript and other original documents and records are kept, in accordance with the Public Records Act, 1958, and the Public Records (Scotland) Act, 1937, in special repositories (archives) in Bracknell, Edinburgh and Belfast. The material in these archives is consulted by a large number of people, from both inside and outside the Office. During the year, for instance, 660 loans were made from the archives at Bracknell.

The Cartographic section prepares diagrams for Meteorological Office publications, for internal memoranda, and for papers contributed to scientific journals by members of the staff. It also prepares data-entry forms, exhibition displays, lecture and training viewfoils and slides as well as the many charts and diagrams, for various areas of the world, that are used for plotting meteorological observations.

Some statistics showing the extent of the work carried out by the Cartographic section are given in Table XVI (page 119).

Professional Training

Policy on the professional and managerial training of the staff of the Meteorological Office is determined by the Meteorological Office Training Board, under the chairmanship of the Director-General. Most professional training is carried out within the Office, either at the Meteorological Office College or at the Meteorological Office School of Technical Training, although some staff attend specialist courses outside the Office, usually for non-meteorological subjects. Staff at the College have good working-level contacts with neighbouring Colleges of Technology, the University of Reading, the British Council and the Royal Naval School of Meteorology and Oceanography.

The Meteorological Office College is situated at Shinfield Park, just south of Reading. It is residential and accommodates just over 100 students. It carries out training for the Office in basic meteorology at all levels as well as in forecasting, observing and related topics. The College is well equipped for lectures, for field work and for practical chart work. It has a cinema which seats 94, two lecture theatres and 13 classrooms including one designed for tuition on instruments. An important part of many courses is the simulation of the working conditions in an operational forecasting office. For this purpose, current meteorological observations, including those from satellite are received from many parts of the world by teleprinter and by facsimile.

The extensive grounds of the College provide room for field work, the siting of meteorological instruments and for recreation. There are excellent social facilities at the College, including a squash court, tennis courts and rooms for table tennis and television. This year one television was equipped to receive Teletext broadcasts.

The number of students completing courses this year was 632. While most courses are designed for staff of the Meteorological Office, they are open to students from other meteorological services, provided that places are available. In terms of student-weeks 27 per cent of training at the College this year was for students from outside the Meteorological Office. The numbers of Meteorological Office trainees and visiting students on each type of course this year are shown in Table XVII (page 119). The general pattern of courses has continued as in previous years. On the Scientific Officers' Course, for graduates with high honours, there were 23 students on the course which finished at the beginning of the year while that which started in the latter part of the year has 19 students, 12 from within the Meteorological Office, 4 from Malaysia and 3 (all PhD) from Hong Kong. The Applied Meteorology Course, for new entrants with degrees or with Higher National Certificates, is designed for support scientists and for staff going into forecasting. The course which finished at the beginning

of the year had 19 students, including one each from Sri Lanka and Trinidad. On the course which ran in the second half of 1978 there were 35 students, including 3 from overseas (Belgium, Jordan and Turkey).

The other course concerned with basic training in forecasting is the Initial Forecasting Course. This year it consisted of 12 men of 9 different nationalities. Only two were from the Meteorological Office. A student from Nigeria, along with two members of the Office took the course as an integral part of the University of Reading Sandwich Course, which leads to an Honours BSc degree in Meteorology. A student from Afghanistan took it as a preliminary to MSc studies at Reading. Minimum entry qualifications for the Sandwich Course are GCE 'A' levels in Mathematics and Physics. The course lasts for 3½ to 4 years and consists of alternating periods of academic and practical work. The latter is undertaken in the Meteorological Office, usually in a forecasting unit although some Office staff may also gain experience in Headquarters Branches. In this way students obtain both a good graduate qualification and training in some practical aspects of meteorology. This year, one member of the Office successfully completed the course.

A few years after their first course, forecasters normally return for an Advanced Forecasting Course to develop their knowledge and increase their professionalism. The course lasts seven weeks. All students on this course who are members of the Office are given an audition by the BBC. Most are Scientific Officers, who are in the field for promotion to Higher Scientific Officer.

To implement the Training Board's policy of providing refresher courses for Higher Scientific Officers at intervals of 5–10 years, three Extension Courses, each lasting four weeks, ran this year. On these courses students revise their knowledge of synoptic meteorology and bring it up to date. They tackle some statistics and work on a project chosen by the student under guidance. This is designed to help forecasters conduct minor investigations at their own stations into the weather in the areas for which they are responsible. These courses were supplemented for the first time this year by two other courses each for Higher Scientific Officers and each lasting three weeks; two Advanced Forecasting (Refresher) Courses were essentially for revision and updating of synoptic knowledge and practice; a Further Extension Course was for Higher Scientific Officers who have completed an Extension Course more than five years previously. It concentrated on giving some insight into the use of numerical weather prediction in day-to-day forecasting practice.

Assistant Scientific Officers who are expected to work initially in support roles in Headquarters and in research teams at outstations attend a four week Basic Assistant Course which includes training in elementary meteorology and some grounding in relevant skills. Two such courses ran this year. New ASOs who will work at forecasting units normally begin their training on an Initial Assistants' course, lasting four weeks, during which they are taught the rudiments of plotting, coding and the making of observations. After about two years they attend the Advanced Assistants' Course which lasts six weeks and provides training in elementary meteorology, more advanced coding, communications, pilot balloon work and elementary instrument maintenance. This year four Initial Courses and five advanced Courses ran at the College. In addition College staff ran one Initial Course at Prestwick. Training is not finished at the end of the course; on-the-job training at outstations forms an essential part of the scheme. A new course ran just once this year and is expected to continue in

future. This is for ASOs of wide experience and is known as the Extension Course for Assistants.

The Station Supervisors' Course continues to play a valuable role both as a refresher course and for Scientific Officers newly promoted to fill supervisory posts. Four courses ran, each of four weeks. The purpose of the course is akin to that of the three week broadening course, known as the Senior Meteorologists' Course for Senior Scientific Officers in forecaster and Support Scientist posts.

The number of new entrants in the Office increased this year. At the College, this brought more people on to Initial Courses. As in earlier years, several courses were arranged for staff from outside the Meteorological Office; for observers who man the Auxiliary Reporting and Climatological stations in the United Kingdom, for Air Traffic Control staff who make weather observations at some aerodromes and for Senior Observers of the Saudi-Arabian Department of Meteorology. A highly successful innovation was a course in the maintenance of meteorological instruments run especially for overseas technicians in co-operation with the World Meteorological Organization, Farnborough (Hampshire) College of Technology, the Office's School of Technical Training at Beaufort Park and the Test and Calibration Laboratory at Bracknell.

Short courses of instruction in observing have been given at auxiliary stations by members of the Observational Requirements and Practices Branch. One such station is in a remote part of the Shetlands: it will give observational support for forecasts provided to the offshore oil industry in that area.

Two pairs of courses (with related on-the-job training) for Meteorological Office staff who use the Office COSMOS computer system were both well attended. Other specialist courses ran in Mediterranean Meteorology, Tropical Meteorology and Meteorological Statistics.

The College has also continued to be used by outside organizations for meetings and conferences with a meteorological relevance, including seminars for the European Centre for Medium-range Weather Forecasting, one for WMO on data management for FGGE and one under the Anglo-Soviet Joint Environmental Protection Agreement. Enquiries concerning this facility and for any of the courses at the College should be addressed to the Principal, Meteorological Office College, Shinfield Park, Reading RG2 9AU.

Those joining the Meteorological Office as Assistant Scientific Officers are expected to improve their academic qualifications in scientific subjects by following part-time courses at Technical Colleges and Colleges of Further Education. The number of staff members released for such part-time study was 137 this year. A further 34 members of staff are taking Open University and other courses in Further Education with assistance under the Civil Service Further Education Scheme. In addition 22 members of staff began or continued a Block Release Course for the Higher National Certificate in Mathematics, Statistics and Computing which was started at the Reading College of Technology in 1974. This course consists of four periods, each of six weeks full-time study, spread over two years. During these periods of full-time study staff live at Shinfield Park. Fifteen staff took their final examination this year and 12 were successful; 3 were referred in one subject. During the year 11 members of the staff were on special leave, with pay, for full-time university studies or to attend Sandwich Courses. In addition 7 have taken advantage of a scheme under which scientists can continue to work in the Office and study for a PhD degree under the joint supervision of the Office and a co-operating university. Support

was also given to five members of the Office to attend one-week Field Study Courses run by the Royal Meteorological Society.

Staff at the College keep abreast of developments in connection with the Technician Education Council's courses which are beginning to replace courses for City and Guilds of London Institute and National Certificate examinations.

Table XVII (page 120) shows the numbers of overseas students who have attended courses at the Meteorological Office College and the School of Technical Training. Most were sponsored by their governments, by WMO or by Overseas Development Aid. In addition 34 underwent practical training on the job in various branches of the Office; they came from 20 different countries and territories and studied subjects including instructional technique, aviation forecasting, numerical weather prediction and the use of computers in climatology. Arrangements were also made for the training of 13 technicians from overseas in the maintenance of instruments.

Technical training continues to be carried out in the Observational Requirements and Practices Branch and in the Operational Instrumentation Branch. The number of newly trained technicians needed to maintain and develop specialized equipment has increased. There were only just enough places on the course which leads to promotion from Assistant Scientific Officer to Radio (Meteorological) Technician. The number of short courses which dealt with specific equipments was greater than last year. These included several on the Mk 3 radiosonde ground station and one on micro-processor based systems. A course on the Plessey WF3 radar was held primarily for American technicians operating in the Third World under the WMO Voluntary Assistance Program.

The staff at outstations which make radio soundings were trained to use the new Mk 3 system. A few senior staff from each station were trained at the first stations to be fitted with the new equipment. The remainder of the staff were then trained at their own stations when the stations were about to become operational. One member of the staff was given a one week course at Beaufort Park in Grawsonde techniques.

The Office continues to support a number of fellowships under the Voluntary Assistance Program of WMO. During the year, four Ethiopians received training in telecommunications as Short Term Fellows and two students on the Instrument Maintenance Course were funded similarly. At the end of the year nine students were being funded as Long Term Fellows: students from the Bahamas, Ecuador, Ghana and Nigeria are reading for first degrees in Meteorology at the University of Reading; MSc courses are being undertaken by students from Afghanistan, Argentina and Barbados. One student from Egypt is continuing his PhD at Reading and one from Turkey is attending the Applied Meteorology Course at Shinfield Park. This year one VAP student gained his MSc at the University of Reading and another his BSc (upper second class Honours in Meteorology).

K. H. STEWART
Director of Research

STATISTICS OF THE RESEARCH DIRECTORATE

TABLE XVI—LIBRARY, ARCHIVES AND CARTOGRAPHIC SECTION

Library

Publications received:	
Daily weather reports	10 759
Books, journals etc.	7498
Slides and photographs	999
Individual books, pamphlets, articles etc. classified and catalogued	9178
Publications lent (excluding 48-hour loans):	
Daily weather reports	15 661
Book, journals etc.	20 270
Slides and photographs	9512
Number of exchange agreements	1120
Number of pages translated by Library translator	440
Russian 202, German 124, French 75, Romanian 39	
Number of pages translated by freelance translators	124
Russian 37, Japanese 22, Italian 28, Dutch 10, Norwegian 10, Hungarian 8, Chinese 5, Spanish 3, Slovak 1	

Archives

Number of loans	660

Cartographic Section

Number of diagrams, maps and charts completed during year	3247
Number of reprographic jobs during year	359

TABLE XVII—TRAINING

The following figures give details of courses completed during 1978 at the Meteorological Office training establishments at Shinfield Park and Beaufort Park.

	Number of courses	Length in weeks	Met. O. staff	Others	Total
Scientific Officers	1	23	18	5	23
Applied Meteorology (Prep)	1	3	6	1	7
Applied Meteorology Part I	1	11	32	3	35
Initial Forecasting	1	18	2	10	12
Advanced Forecasting	3	7	15	8	23
Advanced Forecasting (Refresher)	2	3	18	0	18
Extension Course	3	4	25	2	27
Further Extension Course	1	3	8	0	8
Senior Meteorologists	2	3	33	1	34
Meteorological Statistics	2	4	14	2	16
Tropical Meteorology	1	3	0	7	7
Mediterranean Meteorology	2	3	2	8	10
Initial Programmers	3	4	34	0	34
Second Programmers	1	2	17	0	17
Basic Assistants	2	4	10	0	10
Initial Assistants	5	4	56	2	58
Advanced Assistants	5	6	35	3	38
Extension Assistants	1	4	11	0	11
SO (Supervisors)	3	4	20	1	21
Auxiliary and Co-operating Observers	11	1	0	149	149
Air Traffic Control Staff	3	1	0	31	31
Climat Inspectors	1	1	12	0	12
Met for Tech Staff	1	2	7	0	7

TABLE XVII (*continued*)

	Number of courses	Length in weeks	Met. O. staff	Others	Total
ASO/RMT Conversion	1	23	9	2	11
*ASO/RMT Electronics	1	28	9	3	12
Instrument Maintenance Course ...	1	6	0	13	13
New Equipment Courses:					
MK 3 R/S	5	2½	31	0	31
MOWFR 4	1	4	11	0	11
TD5 MK5	1	2	4	0	4
MODLE 3	1	3	4	0	4
Digital Computing Techniques ...	6	3	13	0	13
Radiosonde:					
Grawsonde Refresher	1	1	1	0	1
Mk 3 Conversion	18	2	37	0	37
Totals			494	251	745

*Course carried out for Meteorological Office by RAF Support Command at RAF Sealand.

Students from the following territories attended courses which terminated during 1978.

	Number of students
Afghanistan	1
Bahamas	1
Bahrain	4
Bangladesh	1
Barbados	2
Belgium	2
Brunei	1
Burma	1
Cyprus	1
Ethiopia	2
Gambia	1
Guyana	1
Hong Kong	7
Isle of Man	1
Jordan	2
Libya	5
Malawi	1
Malaysia	8
Nigeria	1
Qatar	1
Saudi Arabia	11
Sudan	1
Switzerland	1
Syria	4
Tanzania	2
Trinidad	3
Turkey	2
Yemen	1
Zambia	1
Total	70

ADMINISTRATION

Personnel Management

Introduction

Meteorological Office staff serve at over 100 locations in the United Kingdom and overseas. Numbers of staff at each location range from about 1200 in the Headquarters at Bracknell down to single individuals at a few isolated units. This poses a number of management problems very different from those in many other areas of the Civil Service. Personnel management for the majority of staff, including all those in the scientific and technical grades, is undertaken centrally by the Secretary of the Meteorological Office and, under him, the Assistant Director and staff of the Personnel Management Branch at Bracknell. In this way the career prospects of staff and the opportunities open to them do not depend on the size or location of their particular unit. At the same time the Office has maximum flexibility in meeting its varied staff requirements. Some aspects of the personnel management work are outlined in the following paragraphs.

Manning

Movements of most members of the staff are the responsibility of the manning sections at Bracknell, but short-period detachments may be arranged by Principal Meteorological Officers at outstations. The majority of posts at outstations and a substantial number at Headquarters have to be manned for 24 hours a day, 7 days a week, and this requires considerable planning and a high degree of staff mobility. During 1978 the number of postings averaged about 22 a week. Prior consultations with line managers and the career development section help to ensure that, as far as possible, long-term needs and preferences of the individuals are taken into account, as well as meeting short-term requirements.

Career development

Career development panels continued to monitor and guide the careers of staff members for whom they are responsible. In addition to the two main panels for senior and high-potential specialist staff, smaller panels have been established within the Personnel Branch to help with the career development of others. Considerable importance is attached to the successful operation of the staff appraisal system and high priority was given in 1978 to training staff in the skills of staff reporting and appraisal interviewing. One important development was the introduction into the Meteorological Office, in common with other Government Departments, of arrangements for the disclosure, to those officers who request it, of overall performance and promotability ratings from Annual Staff Reports.

During 1978 increasing attention was paid to the training needs of all staff and to the development of a planned schedule of professional and management training as an essential part of career development and planning. Accordingly, the system of recording training and career histories has been improved, using the MOD Civilian Management Information Service (CIPMIS) as a basis.

Records

Personal records of the majority of staff members are held centrally in the records section which is responsible for maintaining up-to-date information on the CIPMIS system. Secretarial work for the various promotion boards in the Meteorological Office is carried out by the records staff, working in co-operation with the career development and manning sections. Some functions, such as approval of special leave, are delegated to Principal Meteorological Officers and other senior line managers. However, all questions on conditions of service and general administration, together with discipline etc., are handled through the records sections.

Manpower planning

Continuous monitoring and planning is required to ensure an efficient level of manning in the Office within the agreed overall complement. Statistics of staff numbers, promotion patterns, recruitment and wastage, have been kept by various sections of the Personnel Branch for a number of years. The provision of these statistics is now closely co-ordinated, and the information is used as the basis for manpower-planning exercises carried out using computer programs developed by the Civil Service Department. Interpretation of the results has an immediate use for recruiting purposes, and, in the longer term, gives indications of likely requirements for training. The system is well suited to the closely knit centrally managed Meteorological Office and can be used to test the effects of possible changes in work patterns on the future career prospects of staff members and on future recruiting requirements.

Recruitment

The Personnel Management Branch is responsible for recruitment, in accordance with regulations laid down by the Civil Service Commission, to most grades for which the Office has a requirement, although recruitment of graduates is undertaken as part of the Commission's centralized recruiting program.

In 1978 the number of permanent and casual staff recruited was more than double that for 1977. However, it became very clear that the Office was competing strongly with other employers in both the public and private sectors for new graduate staff and, although improvements were made to the recruiting process, only 14 graduates were recruited against a target figure of 23. Targets for the 1979 intake will be even larger and greater effort will have to be made if the Office is to attract sufficient graduates of the right calibre. Recruitment to the Assistant Scientific Officer grade on the other hand was much more encouraging, a very large increase in demand being successfully met. Over 1000 requests for application forms were received, resulting in 121 candidates taking up posts in the Office. Other staff joining the Office during the year included 3 in Professional and Technology Officer grades from trawl notices and 21 Clerical Assistants from Open Competitions. Temporary staff included 5 College-based Sandwich Course students undergoing industrial training, and 5 vacation students who were employed for about two months in the summer.

Six university lecturers worked briefly as vacation consultants in research branches.

Staff numbers

At the end of 1978 the total number of posts of all grades was 3265, a decrease of 39 over the year. The actual strength at the end of the year was made up as follows:

Deputy Secretary	1
Under Secretary	2
Science Group	
Chief Scientific Officer	1
Deputy Chief Scientific Officer	5
Senior Principal Scientific Officer	26
Principal Scientific Officer	115
Senior Scientific Officer	282
Higher Scientific Officer	521
Scientific Officer	472
Assistant Scientific Officer	893
Administration Group	
Assistant Secretary	1
Principal	1
Executive grades	34
Clerical grades	145
Marine Staff	
Marine Superintendent	1
Nautical Officer grades	11
Ocean Weather Ships and Base	
Officers and non-industrial grades	46
Crew and industrial grades	43
Professional Engineer Staff	
Principal Professional and Technology Officer	1
Professional and Technology Officer Grade I	3
Professional and Technology Officer Grade II	7
Professional and Technology Officer Grade III	5
Professional and Technology Officer Grade IV	4
Technical and Signals grades	282
Typing and miscellaneous non-industrial grades	138
Industrial employees	88
Locally entered staff and employees overseas	88

Finance

Except for the common services provided by other Government departments as part of their normal functions (i.e. accommodation by the Property Services Agency of the Department of the Environment, and stationery and office machinery by Her Majesty's Stationery Office) the cost of the Meteorological Office is borne by Defence Votes.

In previous *Annual Reports*, financial information has been given in terms of estimated expenditure and receipts in a few broad categories corresponding to MOD vote management areas: staff, equipment etc. This information was of limited value.

With the introduction of a new cost accounting system in April 1978, it has become possible to present financial information in much more detail and in a way which reveals more clearly than before the pattern of spending within the Office. The tables which follow give the operating expenses of the component parts of the Meteorological Office: the cost of carrying out major functions—forecasting, collecting observations, etc.; and the estimated income receivable from repayment services, all for the financial year 1978/79. In future *Reports* a comparison will be made with the expenditure for the previous year.

At the time of going to press, the final accounts for 1978/79 had not been formally approved and the information which follows may be subject to some amendment.

INTERIM STATEMENT OF OPERATING EXPENSES BY METEOROLOGICAL OFFICE FUNCTIONS FOR THE YEAR ENDED 31 MARCH 1979

	£000	£000
Main functions		
1. Making and handling observations	7705	
2. Forecasting	7131	
3. Meteorological (including climatological) advice	3448	
4. Research and development	5694	
	——	23 978
Supporting functions		
5. Administrative and technical support	4965	
6. International activities	1116	
7. Computer services	2010	
8. Telecommunications	3891	
	——	11 982
		35 960

METEOROLOGICAL OFFICE RECEIPTS 1978/79 (CASH RECEIVABLE)

(1)	(2) £000	(3) £000	(4) £000
SERVICES TO:			
Ministry of Agriculture, Fisheries and Food			105
Other Exchequer Departments (Dept of the Environment etc.) ...			47
Civil Aviation Authority			8940
Natural Environment Research Council			31
Other non-Exchequer Departments			27
			9150
Meteorological Office College—Training of meteorologists ...			82
Secondments to outside bodies			87
Comprehensive forecasting service for the offshore oil industry ...		416	
Forecasting services developed to meet individual user's special needs:			
Ship-routeing Service	29		
Gas Boards...	90		
Central Electricity Generating Board	59		
British Rail	8		
Independent Broadcasting Authority	16		
British Broadcasting Corporation	24		
Press	15		
Other customers' special services	34		
	—	275	
Automatic Telephone Weather Service (Post Office)		189	
Issue of forecasts by prior arrangement	6		
Issue of local detailed forecasts by prior arrangement	4		
Issue of forecasts up to 24 hours in advance	56		
Issue of expected occurrences of specified weather (Frost, Fog etc.)	48		
Pigeon racing forecasts	7		
Issue of three-day dry-spell forecasts	6		
Issue of road-danger warnings	28		
Issue of weekend temperature forecasts	4		
Investigations and other professional work as required	82		
Preparation of Weekly, Monthly and Annual Weather Summaries	12		
Preparation of Certified Statements	16		
Outside attendances by professional staff (Court appearances) ...	2		
Supply of copies of data/records	56		
Daily Weather Reports/Publications/Met. forms	7		
Other services	16		
	—	350	
		—	1230
			£10 549

INTERIM STATEMENT OF OPERATING EXPENSES OF THE METEOROLOGICAL

(1) Expenditure	(2) Offices at RAF stations £000	(3) Offices at CAA/ATCC stations £000
1. Personnel (pay, allowances, Ernic and Superannuation) ...	4837	3075
2. Materials (stores, minor equipment, maintenance and ships expenses)	275	159
3. Staff travel and subsistence	114	60
4. Accommodation (DOE—agency basis)...	559	
5. Office support (HMSO—agency basis) (stationery, office machines etc.)	51	36
6. Telecommunications		
7. Equipment support (aircraft and motor transport)	90	
	5926	3330
8. Grants and subscriptions:		
Research Grants		
Grants to World Met. Organization		
Subs to World Met. Organization...		
World Weather Watch upper-air stations Overseas ...		
Subs to ECMWF		
Training expenses of Voluntary Aid Program of World Met. Organization		
European Space Agency METEOSAT Program ...		
First GARP Global Experiment contribution (FGGE) ...		
European Network of Ocean Stations (ENOS)		
Co-operative Automatic Weather Radar		
9. Other expenditure:		
Payment to auxiliary observers		
	5926	3330
10. Depreciation (Historical):		
Equipment	47	23
Computers		
Ships		
Aircraft		
	5973	3353

*Operating expenses of research outstations have been included in column 7.

OFFICE FOR THE YEAR ENDED 31 MARCH 1979

(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Other met.	Met. Office HQ Directorates				
Weather centres	services outstations*	Met. Services	Research*	Admin.	1978/79 Total	1977/78 Total
£000	£000	£000	£000	£000	£000	£000
1059	2909	5874	2999	1513	22 266	21 302
55	1556	799	660	99	3603	3609
21	59	100	61	30	445	510
128	232	825	573	309	2626	2586
13	35	60	34	17	246	228
		1123			1123	955
	36	20	941	47	1134	712
1276	4827	8801	5268	2015	31 443	29 902
			33		33	30
		123			123	74
		393			393	372
		182			182	161
		576			576	452
		41			41	41
		1269			1269	—
		17			17	17
		1			1	—
		41			41	8
		71			71	63
1276	4827	11 515	5301	2015	34 190	31 120
7	161	105	98	1	442	432
		575	9		584	572
	492				492	492
			252		252	252
1283	5480	12 195	5660	2016	35 960	32 868

A. C. HUGHES
Secretary,
Meteorological Office

INTERNATIONAL CO-OPERATION

The year was one of increased activity as the four year cycle of work in the World Meteorological Organization (WMO) approached its end. Of the WMO Technical Commissions, the Commission for Atmospheric Sciences held its Seventh Session in Manila, Philippines between 2 and 10 February. Dr K. H. Stewart, Director of Research, led the UK delegation which included Dr D. J. Carson of the Meteorological Office and Professor R. P. Pearce of Reading University. The Seventh Session of the Commission for Special Applications of Meteorology and Climatology met in Geneva between 17 and 28 April and the UK delegation led by Dr N. E. Rider, Deputy Director (Observations), included Mr R. J. Ogden, Assistant Director (Climatological Services), and Mr R. N. Hardy. The Seventh Session of the Commission for Basic Systems met in Washington between 6 and 17 November 1978; the UK delegation was led by Mr F. H. Bushby, Director of Services, and included Mr D. R. Grant, Assistant Director (Observational Practices), Mr D. McNaughton, Assistant Director (Telecommunications), and Lieutenant Commander E. J. Cuerden of the Directorate of Naval Oceanography and Meteorology.

The United Kingdom sent a delegation to the Seventh Session of WMO Regional Association VI (Europe) which met in Prague, Czechoslovakia between 17 and 25 October 1978. The delegation was led by Mr D. E. Jones, Assistant Director (Central Forecasting) and included Mr D. McNaughton and Mr G. J. Day, Assistant Director (International and Planning). Mr D. J. Clark attended the Seventh Session of Regional Association I (Africa) between 6 and 17 February.

The United Kingdom sent a delegation to the Thirtieth Session of the Executive Committee (EC XXX) and its Preparatory Committee which was held in Geneva between 25 May and 15 June. The delegation was led by the Director-General and included Mr A. C. Hughes, Secretary of the Meteorological Office and Mr G. J. Day. EC XXX gave considerable attention to the proposed World Climate Program which is to be discussed at the forthcoming WMO Eighth Congress and to the World Climate Conference which is to precede it.

The Council of the European Centre for Medium-range Weather Forecasts (ECMWF) met in London on 4 and 5 May and 21 and 22 November. On both occasions the United Kingdom delegation was led by the Director-General and included members of the Office staff and representatives of the Personnel Management and the Finance Branches of the Ministry of Defence.

Members of the Office and staff of the Ministry of Defence continue to work on various ECMWF Committees. These include Mr F. H. Bushby who is a member of the Scientific Advisory Committee and was Chairman of the Advisory Committee for the Use of the Computing System and Dr R. L. Wiley, Assistant Director (Systems Development), who is the Chairman of the Communications Advisory Committee. An ECMWF Symposium on the Interpretation and Use of Large-scale Numerical Forecast Products was held at Shinfield Park from 4 to 8 September and a Workshop on Parametrization of Cumulus Convection was held from 23 to 25 October. Both were attended by specialists from the Office.

The Director-General attended the Eighth Informal Meeting of the Western European Directors of Meteorological Services held in Reykjavik, Iceland between 9 and 11 May 1978.

Work on meteorological projects within the European Co-operation in Science and Technology (COST) continued at a rather lower level than recently. Mr G. A. Clift attended the Project 72 Technical Committee in Brussels on 1 and 2 August for which he has produced a report on the Concept of a (European) Weather Radar Network. Project 43, Oceanography and Meteorology, is approaching an operational phase and Dr D. N. Axford attended the Interim Management meetings in Brussels in February and May and Dr R. E. W. Pettifer that in Lisbon in December.

Activity in connection with the Global Atmospheric Research Program (GARP) has continued. In connection with the First GARP Global Experiment (FGGE) Mr M. V. Jones attended meetings of the Working Group on Data Management at Shinfield Park from 12 to 16 June and in Moscow from 20 to 24 November. Mr F. H. Bushby attended a meeting of the FGGE Board in Bracknell from 4 to 6 September and Dr N. E. Rider represented the UK at a meeting of the WMO Inter-governmental Panel on FGGE in Geneva in June.

Assistance for developing countries within the WMO technical co-operation program continues and consideration has been given to measures to improve the effectiveness of the assistance given. In consequence Mr D. J. Clark spent three weeks during November visiting selected African countries to study the local conditions and to discuss possible aid projects with the authorities concerned.

Other WMO meetings or joint WMO meetings with other international bodies, in which the Meteorological Office staff took part, were as follows:

Subject	*Place and date*	*Attended by*
Executive Committee Working Group on Cloud Physics and Weather Modification	Geneva January	Mr P. Goldsmith, Deputy Director (Physical Research)
CBS Joint Study Group on Minimum Standards for Quality Control	Geneva January–February	Mr D. J. Painting (Met O 3)
First Session of the RA VI Working Group on Co-ordination of Requirements for Data in GRID Code Form	Geneva February	Dr A. J. Gadd (Met O 2)
WMO/IIASA Workshop on Carbon Dioxide, Climate and Society	Laxenburg, Austria February	Dr P. R. Rowntree (Met O 20)
CBS Working Group on GOS	Geneva March	Mr D. R. Grant, Assistant Director (Observational Requirements and Practices)
Joint IOC/WMO Meeting of Governmental Experts on IGOSS Data Processing and Services Systems	Hamburg March	Dr K. M. Carpenter (Met O 11)
Joint IOC/WMO Subgroup of Experts on IGOSS Products and Services in Support of GARP	Hamburg March	Dr K. M. Carpenter (Met O 11)
Fourth Session of the CBS Working Group on the Global Data-processing System	Geneva March–April	Mr D. E. Jones, Assistant Director (Central Forecasting)
North Atlantic Ocean Stations (NAOS) Working Group Meeting on Future of NAOS after 1981	Geneva April	Captain G. A. White, Marine Superintendent

Subject	*Place and date*	*Attended by*
Third Session of the CMM Working Group on Marine Meteorological Services	Geneva April	Captain G. A. White, Marine Superintendent
Board of the Precipitation Enhancement Project	Geneva April	Mr P. Goldsmith, Deputy Director (Physical Research)
JOC Study Conference on Climate Models	Washington, D.C. April	Mr A. Gilchrist, Deputy Director (Dynamical Research) Mr P. Rowntree (Met O 20)
JOC Working Group on Numerical Experimentation—Sixteenth Session	Washington, D.C. April	Mr F. H. Bushby, Deputy Director (Forecasting Services)
CBS Study Group on Coded Digital and Analogue Facsimile	Moscow May	Mr C. E. Goodison (Met O 5)
CBS Study Group on Data Transmission Techniques	Moscow May	Mr R. D. Sowden (Met O 5)
Twenty-first Meeting of COSPAR and Symposium on Remote Sounding of the Atmosphere from Space	Innsbruck June	Mr D. E. Miller, Assistant Director (High Atmosphere) Dr D. R. Pick (Met O 19)
Symposium on Physical Processes in the Atmospheric Boundary Layer	Norrköping, Sweden June	Dr P. J. Mason (Met O 14)
Symposium on the Geophysical Aspects and Consequences of Changes in the Composition of the Stratosphere	Toronto June	Mr P. Graystone, Assistant Director (Dynamical Climatology) Dr A. F. Tuck (Met O 15)
NAOS Board	Geneva July	Dr N. E. Rider, Deputy Director (Observational Services) Mr K. Sheppard (Met O 4)
Intercomparison of European Dobson Ozone Spectrophotometers, Organized by RA VI Working Group on Atmospheric Ozone	Arosa August	Dr E. L. Simmons (Met O 19) Mr J. H. Convery (Met O 19)
JOC Study Conference on the Parametrization of Extended Cloudiness and Radiation in Climate Models	Oxford September–October	Mr A. Gilchrist, Deputy Director (Dynamical Research) Mr P. Goldsmith, Deputy Director (Physical Research) Dr P. Ryder, Assistant Director (Cloud Physics) Mr R. Brown (Met O 15)
CIMO Working Group on the Education and Training of Instrument Specialists	Geneva October	Mrs J. V. Hurst (Registrar, Met O College)
Informal Planning Meeting on Codes, Message Identifiers and Related Matters	Geneva October	Dr R. L. Wiley, Assistant Director (Systems Development)
Second Evaluation of Delayed Data Flow for the FGGE	Norrköping, Sweden November	Mr J. Ballentine (Met O 12)

Attendances not already listed, at international conferences sponsored wholly or primarily by bodies other than WMO, and other visits abroad, were as follows:

Subject	*Place and date*	*Attended by*
NATO, AAFCE, ATOC Sub-group	Maastricht January	Mr D. Forsdyke (Met O 6)
EUROCONTROL	Brussels January	Dr D. A. Forrester (Met O 2)

Subject	*Place and date*	*Attended by*
NATO MCMG Working Group on Weather Communications—Sub-group I	Brussels January	Mr C. E. Goodison (Met O 5)
Ad hoc Meeting at JRC to Discuss Final Report on Stratospheric Modelling Supplied under contract by Meteorological Office	Ispra, Italy January	Dr R. J. Murgatroyd (Met O 20)
NATO Group of Experts on Fallout Warning Exercises	Luxembourg January	Mr P. G. Rackliff (Met O 6)
ESA Meteorological Satellite Program Board	Paris January, May, September, November	Dr K. H. Stewart, Director of Research
NATO MCMG Sub-group VII	Bracknell February	Mr J. G. Moore (Met O 2) Dr D. A. Forrester (Met O 2) Mr D. W. Tann (Met O 6)
	Traben-Trarbach, West Germany April	Mr J. G. Moore (Met O 2)
CEC Meeting on European Research on Ozone Shield Depletion Problem Study Group III	Brussels February, April, May, October	Mr P. Graystone, Assistant Director (Dynamical Climatology) Dr R. J. Murgatroyd (Consultant) Dr S. A. Clough (Met O 20)
Visit in connection with Weather Radar	Jersey February	Mr G. A. Clift (Met O 16)
ECMWF ACUCS—First Session	Bracknell February	Mr F. H. Bushby, Deputy Director (Forecasting Services)
First Meeting of the Meteorological Advisory Group to the European Air Navigation Planning Group of ICAO	Paris February	Mr C. H. Hinkel (Met O 7)
Oceanology International Conference, Brighton	Brighton March	Dr J. S. Foot (Met O 16) Dr R. E. W. Pettifer (Met O 16) Mr K. J. T. Sands (Met O 16) Mr M. J. Kerley (Met O 16) Mr R. M. Morris (Met O 7)
NATO MCMG Working Groups	Izmir March, April	Mr D. W. Tann (Met O 6) Mr C. E. Goodison (Met O 5)
NOAA Upper Air Branch Discussion on Stratospheric Analysis Techniques	Washington, D.C. March	Mr J. S. Campbell (Met O 19)
AGARD Propulsion and Energetics Panel 51st(A) Specialists Meeting on Icing Testing for Aircraft Engines	London April	Dr W. T. Roach, Assistant Director (Special Investigations) Dr P. Ryder, Assistant Director (Cloud Physics)
European meeting on the Use of Ocean Data Acquisition Systems (ODAS)	Oslo April	Dr R. E. W. Pettifer (Met O 16)
NATO School on Instruments and Methods of Air–Sea Interaction	Ustaoset, Norway April	Dr N. Thompson (Met O 8) Mr G. J. Jenkins (Met O 14)
International Conference on Urban Storm Drainage	Southampton University April	Mr C. K. Folland (Met O 8)
NATO AFCENT Meteorological Committee	Traben-Trarbach, West Germany April	Mr D. Forsdyke (Met O 6) Mr K. Pollard (Met O 6)
IBM Seminar of Major European Users of Computers for Scientific Purposes	Monaco April	Dr R. L. Wiley (Met O 22)

Subject	*Place and date*	*Attended by*
Meeting of the Advisory Group for Co-ordination in Europe on the Reception and Evaluation of Information from Satellites	Rome April	Mr A. I. Johnson (Met O 19)
AGARD—The Application of Inexpensive Minicomputers to Information Work	Delft April	Mr E. W. C. Harris (Librarian)
IIASA Workshop on Climate Issues	Laxenburg, Austria April	Dr B. J. Mason, Director-General
ESA Space Meteorology Working Group	Paris April, May	Dr K. H. Stewart, Director of Research
ESA Scientific Technical and Advisory Group	Paris April, September	Dr K. H. Stewart, Director of Research
NATO ACE Command Meteorological Officers Sub-committee	Mons May	Mr W. G. Durbin (Met O 6)
Working Group on Land Surface Processes in Climate Modelling	Dublin May	Mr P. R. Rowntree (Met O 20)
Meeting of the Steering Committee of SCOSTEP/MAP	Innsbruck May	Dr R. J. Murgatroyd (representing IAMAP) (Met O 20)
Consultation on Mesoscale Modelling	USA May	Dr K. M. Carpenter (Met O 11)
Twelfth Meeting of the MOTNE Working Group on ICAO	Paris May	Mr K. Bryant (Met O 7)
ECMWF Sponsored Seminar of Telecommunication Protocols	Shinfield Park May	Dr R. L. Wiley (Met O 22)
Dutch–German Joint Air Pollution Project Meeting	Kettwig, West Germany May	Dr F. B. Smith, Assistant Director (Boundary Layer)
ECE Long-range Transmission of Air Pollutants Working Group Meeting	Bildhoven, The Netherlands May	Dr F. B. Smith, Assistant Director (Boundary Layer)
IIASA Council	Vienna May/June	Dr B. J. Mason, Director-General
COSPAR 21st Plenary Meeting Symposium on Remote Sounding of Atmosphere from Space	Innsbruck June	Miss M. J. Atkins (Met O 2)
European Grassland Federation	Ghent June	Miss M. G. Roy (Met O 8)
NATO Nuclear Fallout Exercise Co-ordination Meeting (INTEX)	London June	Mr P .G. Rackliff (Met O 6)
NATO MCMG	Brussels June	Mr I. J. W. Pothecary, Assistant Director (Defence Services) Mr D. W. Tann (Met O 6) Mr C. E. Goodison (Met O 5)
EEC Intercomparison of Reference Radiation Instruments	Carpentras, France June	Mr B. R. May (Met O 1) Mr H. E. Painter (Met O 1)
Icing Specialist Workshop Conference, NASA	USA July	Dr P. Ryder, Assistant Director (Cloud Physics)
NATO MCMG Working Group on Weather Communications—Subgroup III	Paris July	Mr C. E. Goodison (Met O 5)
Visit to Air Force Geophysical Research Laboratory	Boston, Mass., Washington, D.C. July	Dr J. S. Foot (Met O 16)
Anglo-Soviet Environmental Protection Agreement—Visit of Experts	London July	Dr F. B. Smith, Assistant Director (Boundary Layer)
ECMWF SAC Sixth Session	London August	Mr F. H. Bushby, Director of Services

Subject	*Place and date*	*Attended by*
NATO SHAPE Meteorological Committee	Mons August	Mr D. W. Tann (Met O 6) Mr W. G. Durbin (Met O 6)
Twelfth International Congress of Mathematical Geophysics	Caracas, Venezuela August	Dr R. Hide, Head of Met O 21
Conference on Meteorology over the Tropical Oceans	London August	Dr P. R. Jonas (Met O 21) Dr B. J. Mason, Director-General Dr K. H. Stewart, Director of Research Mr A. Gilchrist, Deputy Director (Dynamical Research) Dr K. A. Browning, C Met O (Met O RRL) Mr P. Graystone, Assistant Director (Dynamical Climatology) Dr P. Ryder, Assistant Director (Cloud Physics) Dr D. J. Carson (Met O 20) Mr D. B. Shaw (Met O 20) Dr J. F. B. Mitchell (Met O 20) Mrs J. M. Slingo (Met O 20) Mr A. O'Neill (Met O 20) Mr J. R. Whiteway (Met O 20) Mr W. M. Cunnington (Met O 20) Mr M. R. Newman (Met O 20) Mr W. N. C. Keeping (Met O 20) Mr J. A. Bolton (Met O 20) Dr P. R. Rowntree (Met O 20) Dr K. M. Carpenter (Met O 11) Dr T. Davies (Met O 11) Dr C. J. Readings (Meteorological Research Flight) Mr S. Nicholls (Meteorological Research Flight) Mr A. F. Jenkinson (Met O 13)
Fifth Meeting of the European Geophysical Society	Strasbourg August, September	Mr J. C. King (Met O 21)
NATO Army Armaments Group AC 225 Panel XII	Brussels September	Mr P. G. Rackliff (Met O 6)
European Mechanics Colloquium 105	Grenoble September	Dr P. R. Jonas (Met O 21)
European Mechanics Colloquium 106	Grenoble September	Dr P. R. Jonas (Met O 21)
Seminar on Ocean Wave Generation and Numerical Modelling of Sea and Swell	Dublin September	Mr B. W. Golding (Met O 2)
US Army Meso-met Advisory Panel	Las Cruces, N. Mex. September	Dr P. W. White, Assistant Director (Forecasting Research)
CENTO 1978 Meteorological Coordination Conference	Tehran September	Mr D. W. Tann (Met O 6)
European Symposium of the Digital Corporation Users Society	Copenhagen September	Mr J. F. Ponting (Met O 22)

Subject	*Place and date*	*Attended by*
Fourth Session of the Advisory Committee on Matters Related to Communications between ECMWF and Member States	Offenbach September	Dr R. L. Wiley, Assistant Director (Systems Development)
Mathematical Modelling of Turbulent Diffusion in the Environment	Liverpool September	Dr F. B. Smith, Assistant Director (Boundary Layer)
EEC Solar Energy Program Project F	Paris September	Mr B. R. May (Met O 1)
ECMWF ACUCS Second Session	Bracknell September	Mr F. H. Bushby, Director of Services
Second Meeting of the Meteorological Advisory Group to the European Air Navigation Planning Group of ICAO	Paris September	Mr P. D. Borrett (Met O 7)
NMC Washington and NESS	Washington, D.C. September	Mr D. M. Houghton, Assistant Director (Synoptic Climatology)
European Physical Society Conference	York September	Dr B. J. Mason, Director-General
XVII ICSU General Assembly	Athens September	Dr B. J. Mason, Director-General
NATO MCMG Working Groups	Ottawa September, October	Mr D. W. Tann (Met O 6) Mr C. E. Goodison (Met O 5)
International Conference on Atmospheric Sensing with Lasers	London October	Dr D. N. Axford, Assistant Director (Operational Instrumentation) Dr R. E. W. Pettifer (Met O 16) Dr J. S. Foot (Met O 16)
European Offshore Petroleum Conference Exhibition	London October	Dr J. S. Foot (Met O 16) Mr R. Scofield (Met O 16) Mr B. Van Biene (Met O 16)
Second Conference on Atmospheric and Oceanic Waves and Stability	Boston, Mass. October	Dr I. N. James (Met O 21)
CEC Meeting on European Research on the Ozone Shield Depletion Problem	Brussels October	Dr R. J. Murgatroyd (Consultant) and Dr S. A. Clough (Met O 20)
IEA Solar Energy Program	Hamburg October	Mr B. R. May (Met O 1)
American Meteorological Society Conference on Weather Forecasting and Analysis and Aviation Meteorology	Silver Spring, Md October	Dr K. A. Browning, C Met O (Met O RRL) Mr C. G. Collier (Met O RRL)
Conference on Meteorology and Oceanography Applied to the Engineering Installations and Operation of Offshore Structures	The Hague October–November	Dr B. J. Mason, Director-General Mr D. M. Houghton, Assistant Director (Synoptic Climatology) Dr D. N. Axford, Assistant Director (Operational Instrumentation) Dr R. E. W. Pettifer (Met O 16) Mr D. J. Painting (Met O 3) Mr R. M. Morris (Met O 7)
Second Meeting of North Sea Meteorological Panel	Shinfield Park October	Mr R. J. Ogden, Assistant Director (Public Services) Mr R. D. Hunt (Met O 7) Mr R. M. Morris (Met O 7)
Meeting of Directors of METEOSAT Countries	Paris October	Dr B. J. Mason, Director-General
ECMWF Finance Committee	London October	Mr G. J. Day, Assistant Director (International and Planning)

Subject	*Place and date*	*Attended by*
NATO MCMG Working Group on Weather Communications—Sub-group II	Traben-Trarbach November	Mr C. E. Goodison (Met O 5)
NATO Army Armaments Group Panel X, Helicopter Icing Sub-group, Symposium on Helicopter Icing	London November	Dr W. T. Roach, Assistant Director (Special Investigations) Dr P. Ryder, Assistant Director (Cloud Physics)
Prospectives of Physical Chemistry	London November	Dr A. F. Tuck (Met O 15)
Meeting at the Danish Atomic Energy Department	Risø November	Dr P. J. Mason (Met O 14)
Meeting of Ground-truth Group for NASA Stratospheric Aerosol and Gas Experiment	Brussels November	Mr D. E. Miller, Assistant Director (High Atmosphere)
EEC Solar Energy Program Project F	Brussels November	Mr B. R. May (Met O 1)
Meeting of US Federal Aviation Authority's Scientific Advisory Committee on their High Altitude Pollution Program	Washington, D.C. November–December	Dr R. J. Murgatroyd, Consultant (Met O 20)
UNEP Co-ordinating Meeting on the Ozone Layer	Bonn November–December	Mr P. Graystone, Assistant Director (Dynamical Climatology)

The following staff were released by the Office during 1978 for service with international and other organizations:

Mr R. Cooper	Higher Scientific Officer	Brunei
Mr B. D. Mason	Higher Scientific Officer	European Space Agency
Mr G. D. Whitelock	Assistant Scientific Officer	The Royal Society Aldabra Research Station

Staff returning from international and other secondment appointments were:

Mr J. Findlater	Senior Scientific Officer	Kenya
Mr C. F. Neave	Senior Scientific Officer	Fiji
Mr E. L. Evans	Senior Scientific Officer	Fiji
Mr W. P. Wakelin	Higher Scientific Officer	International Aeradio Ltd
Mr D. E. Pritchard	Higher Scientific Officer	International Aeradio Ltd
Mr A. C. Jones	Higher Scientific Officer	International Aeradio Ltd
Mr S. Nicholls	Higher Scientific Officer	NCAR Boulder, Colorado
Mr J. Hayhurst	Temporary Scientific Officer	New Hebrides
Mr E. S. Spain	Scientific Officer	Zambia
Mr W. K. Young	Scientific Officer	WMO Geneva
Mr R. Greener	Telecommunication Technical Officer III	New Hebrides
Mr G. C. Turner	Assistant Scientific Officer	The Royal Society Aldabra Research Station

HONOURS AND DISTINCTIONS

Dr K. A. Browning was elected a Fellow of the Royal Society.

The L. G. Groves Memorial Prize for Meteorology was awarded to Dr A. F. Tuck and Mr F. P. Sims received the L. G. Groves Second Memorial Award. Mr D. B. Hatton received the Meteorological Observer's Award.

APPENDIX I

BOOKS OR PAPERS BY MEMBERS OF THE STAFF

ADAMS, R. J., Ph.D.; The importance of the weather in aerial crop spraying. *Aeronaut J*, **82,** 1978, 265–266.

ADAMS, R. J., Ph.D.; Meteorological aspects of changes in spraying techniques. *Proc Br Crop Prot Conf, Weeds*, Brighton, November 1978.

ATKINS, J. E.; Development of work on ocean currents. *Mar Obs*, **48,** 1978, 196–203.

BADER, M. J. [M.], M.Sc., DOUGLAS, H. A., B.Sc. and KERLEY, M. J.; The United Kingdom National Data Buoy (DB1). A future source of meteorological data? *Weather*, **33,** 1978, 353–361.

BELL, R. S.; The forecasting of orographically enhanced rainfall accumulations using 10-level model data. *Meteorol Mag*, **107,** 1978, 113–124.

BOOTH, B. J.; On forecasting dry thermals for gliding. *Meteorol Mag*, **107,** 1978, 48–61.

BRADBURY, T. A. M.; A good soaring guide: some cross-country soaring statistics. *Sailpl Gliding*, **29,** 1978, 155–159.

BRADBURY, T. A. M.; Weather conditions for long gliding flights over England. *Meteorol Mag*, **107,** 1978, 340–353.

BRITTAIN, O. W.; Forecasting sea-breezes at Eskmeals. *Meteorol Mag*, **107,** 1978, 88–96.

BROWNING, K. A., Ph.D., D.I.C., F.R.S.; Meteorological applications of radar. London, Institute of Physics, *Rep Prog Phys*, **41,** 1978, 761–806.

BROWNING, K. A., Ph.D., D.I.C., F.R.S.; The structure and mechanisms of hailstorms. *Meteorol Monogr, Boston, Mass*, **16,** No. 38, 1977, 1–43.

BROWNING, K. A., Ph.D., D.I.C., F.R.S., JAMES, P. K., PARKES, D. M., ROWLEY, C. and WHYMAN, A. J.; Observations of strong wind shear using pulse compression radar. *Nature, London*, **271,** 1978, 529–531.

BROWNING, K. A., Ph.D., D.I.C., F.R.S., BUSSELL, R. B. and COLE, J. A.; Radar for rain forecasting and river management. *Water Power & Dam Constr, London*, December 1977.

BROWNING, K. A., Ph.D., D.I.C., F.R.S., *in* JAMES, P. K., WHYMAN, A. J. and BROWNING, K. A.; Radar for clear air measurements. *Phys Bull, New York*, **29,** 1978, 209–210.

BURT, S. D.; The blizzards of February 1978 in south western Britain. *J Meteorol, Trowbridge*, **3,** 1978, 261–278.

BURTON, B. J.; An examination of the mechanism for snow showers at high screen temperatures. *J Meteorol, Trowbridge*, **3,** 1978, 7–13.

CAMPBELL, S., B.Sc. and MAY, B. R., B.Sc.; Determination of the optimum field of view and spacing between observations for a satellite-borne scanning radiometer observing the stratosphere. *Remote Sensing Environ, New York*, **6,** 1977, 157–167.

CARSON, D. J., Ph.D., and RICHARDS, P. J. R.; Modelling surface turbulent fluxes in stable conditions. *Boundary-Layer Meteorol, Dordrecht*, **14,** 1978, 67–81.

CARTER, R. D., B.Sc. and BRIDGE, G. C.; Stratospheric cirrostratus over Scotland. *Weather*, **33,** 1978, 309–315 and 317–318.

CATON, P. G. F. [P.], Ph.D.; Analysis of historic sea surface temperature data. *Ocean Modelling, Cambridge*, **14,** 1978, 9–10.

CAUGHEY, S. J., Ph.D., CREASE, B. A., M.Sc., ASIMAKOPOULOS, D. N. and COLE, R. S.; Quantitative bistatic acoustic sounding of the atmospheric boundary layer. *Q J R Meteorol Soc*, **104,** 1978, 147–161.

CAUGHEY, S. J., Ph.D., DARE, W. M. and CREASE, B. A., M.Sc.; Acoustic sounding of radiation fog. *Meteorol Mag*, **107,** 1978, 103–113.

CHORLEY, L. G.; The Newmarket tornado of 3 January 1978. *Meteorol Mag*, **107**, 1978, 308–313.

CLULEY, A. P., Ph.D. and OLIVER, M. J.; Aircraft measurements of humidity in the low stratosphere over southern England 1972–1976. *Q J R Meteorol Soc*, **104**, 1978, 511–526.

COCHRANE, J., *in* PHIPPS, R. H. and COCHRANE, J.; A note on the effect of bitumen mulch on soil temperature and forage maize production. *Agric Meteorol, Amsterdam*, **17**, 1976, 397–399.

COLLIER, C. G., B.Sc., A.R.C.S. and BROWNING, K. A., Ph.D., D.I.C., F.R.S.; The short-period weather forecasting pilot project and its relevance to storm sewer operation. University of Southampton, Department of Civil Engineering, International Conference on Urban Storm Drainage, 11–14 April 1978, 1978, 42–50.

COLLIER, C. G., B.Sc., A.R.C.S. and LARKE, P. R.; A case study of the measurement of snowfall by radar: an assessment of accuracy. *Q J R Meteorol Soc*, **104**, 1978, 615–621.

COLLIER, C. G., B.Sc., A.R.C.S. *in* BUSSELL, R. B., COLE, J. A. and COLLIER, C. G.; The potential benefit from a national network of precipitation radars and short period forecasting (paper presented at the Cranfield Conference of River Engineers, July 1978). London, MAFF, 1978.

COLLINGBOURNE, R. H., M.Sc., D.I.C.; Wind data available in the Meteorological Office. *J Ind Aerodyn, Amsterdam*, **3**, 1978, 145–155.

COWLEY, J. P., M.Sc.; The distribution over Great Britain of global solar irradiation on a horizontal surface. *Meteorol Mag*, **107**, 1978, 357–373.

CREASE, B. A., M.Sc. and CAUGHEY, S. J., Ph.D., *in* ASIMAKOPOULOS, D. N., COLE, R. S., CREASE, B. A. and CAUGHEY, S. J.; A comparison of acoustic Doppler vertical velocity power spectra with direct measurements. *Atmos Environ, Oxford*, **12**, 1978, 1951–1956.

CULLEN, M. J., Ph.D. and MORTON, K. W.; Analysis of evolutionary error in finite error and other methods. Madison, Wis., University of Wisconsin, *Math Res Cent, MRC Tech Summ Rep* 1832, 1978.

DAWE, A. J.; Cold spell in June 1977. *Weather*, **33**, 1978, 112.

DOUGLAS, H. A., B.Sc. and BADER, M. J. [M.], M.Sc.; An assessment of the meteorological sensors on DB1. Wormley, Institute of Oceanographic Sciences, Report No. 44, 1977.

DOUGLAS, H. A., B.Sc. and OFFILER, D.; The Mk 3 cloud-base recorder—a report on some of the potential accuracy limitations of this instrument. *Meteorol Mag*, **107**, 1978, 23–32.

DOUGLAS, H. A., B.Sc., JEFFREY, D. J. and JEZZARD, F.; The measurement of fog on motorways. *Meteorol Mag*, **107**, 1978, 242–249.

FLAVELL, R. G.; Preliminary results of a six-year study of the lower troposphere over southern England in terms of radio refractive index and potential refractive index. London, Institution of Electronic and Radio Engineers, *IERE Conf Proc* No. 40, 1978, 265–279.

FOLLAND, C. K., B.Sc., M.Inst.P.; Rainfall profiles recommended in Road Note 35. *Chartered Munic Eng*, **105**, 1978, 169–174.

FOLLAND, C. K., B.Sc., M.Inst.P. and COLGATE, M. G., B.Sc.; Recent and planned rainfall studies in the Meteorological Office with an application to urban drainage design. International Conference on Urban Storm Drainage, University of Southampton, Department of Civil Engineering, 11–14 April 1978, 1978, 51–70.

FOLLAND, C. K., B.Sc., M.Inst.P., HARROLD, T. W., Ph.D., D.I.C. and HOOPER, A. H.; Modern raingauge equipment and practice in the Meteorological Office. *J Inst Water Eng Sci*, **32**, 1978, 233–238.

FOLLAND, C. K., B.Sc., M.Inst.P. and WALES-SMITH, B. G.; Hydrological studies on some river catchments in Greater London. Comment on a paper by BUTTERS, K. and VAIRAVAMOORTHY, V. *Proc Inst Civ Eng*, Part 2, **65**, 1978, 475–477.

GADD, A. J., Ph.D.; A numerical advection scheme with small phase speed errors. *Q J R Meteorol Soc*, **104,** 1978, 583–594.

GADD, A. J., Ph.D.; A split explicit integration scheme for numerical weather prediction. *Q J R Meteorol Soc*, **104,** 569–582.

GILCHRIST, A., M.A.; Numerical simulation of climate and climatic change. *Nature, London*, **276,** 1978, 342–345.

GILCHRIST, A., M.A. and LORENC, A. C., B.A.; Results of some observing simulated experiments to study the tropical wind data requirements for the First GARP Global Experiment. ICSU/WMO, GARP Working Group on Numerical Experimentation, Report No. 10, 1975, 69–96.

GILES, W. G.; Weather observation. Wakefield, EP Publishing Ltd., 1978.

GRANT, K., B.A.; A September monsoon depression at Masirah, Oman. *Meteorol Mag*, **107,** 1978, 218–222.

GRAYSTONE, P., B.A.; Studies of stratospheric chemistry using a hemisheric model. Geneva, World Meteorological Organization. Papers presented at the WMO Symposium on the geophysical aspects and consequences of changes in the composition of the stratosphere, Toronto, 26–30 June 1978, 1978, 233–238.

GRINDLEY, J., B.A.; The rainfall of 1977 over the United Kingdom. *The Times, London*, 28 January 1978.

GROVES, K. S., MATTINGLY, S. R., Ph.D. and TUCK, A. F., Ph.D.; Increased atmospheric carbon dioxide and stratospheric ozone. *Nature, London*, **273,** 1978, 711–715.

GROVES, K. S., MATTINGLY, S. R., Ph.D. and TUCK, A. F., Ph.D.; Increasing atmospheric CO_2 and stratospheric ozone. Geneva, World Meteorological Organization. Papers presented at the WMO Symposium on the geophysical aspects and consequences of changes in the composition of the stratosphere, Toronto, 26–30 June 1978, 1978, 255–261.

HALL, C. D.; Visibility at sea and its relationships with spray evaporation in strong winds. Porton, Chemical Defence Experimental Establishment, *Tech Note* No. 207, 1974.

HARRIS, E. [W.C.]; Automation in the National Meteorological Library. London, Circle of State Librarians, *State Libr*, **26,** 1978, 23–24.

HAWORTH, C., B.Sc.; Some relationships between sea surface temperature anomalies and surface pressure anomalies. *Q J R Meteorol Soc*, **104,** 1978, 131–146.

HIDE, R., Sc.D., F.R.S.; An experimental study of thermal convection in a rotating liquid. *Philos Trans R Soc*, A, **250,** 1978, No. 983, 441–478.

HIDE, R., Sc.D., F.R.S.; How to locate the electrically conducting fluid core of a planet from external magnetic observations. *Nature, London*, **271,** 1978, 640–641.

HIDE, R., Sc.D., F.R.S.; On the Earth's deep interior and geomagnetism. European Space Agency, ESA SP-137, 1978, 245–246.

HIDE, R., Sc.D., F.R.S. and MASON, P. J., Ph.D.; On the transition between axisymmetric and non-axisymmetric flow in a rotating liquid annulus subject to a horizontal temperature gradient. *Geophys Astrophys Fluid Dynam, London*, **10,** 1978, 121–156.

HIDE, R., Sc.D., F.R.S. and PLUMB, R. A., Ph.D.; A note on deep Kelvin waves and their propagation through a shear flow. *Geofis Int, Mexico*, **15,** 1975, 375–385.

HOUGH, M. N., Ph.D.; Climatic limitations to the growth of newer crops. *Kent Focus*, MAFF, 1978.

HOUGH, M. N., Ph.D.; Weather conditions. London, Home Grown Cereals Authority. The quality of wheat and barley from the 1977 harvest, 1978, 6–7.

HOUGHTON, D. M., M.Sc., D.I.C.; Weather map of the British Isles. Edinburgh, John Bartholomew and Son Ltd, 1978.

HUNT, G. E., Ph.D.; Meeting report. Workshop on role of cloudiness in climatic change. National Center for Atmospheric Research, Boulder, Col., 14–18 July 1975, Bracknell, 1975.

JACKSON, M. C., M.Sc.; The influence of snowmelt on flood flows in rivers. *J Inst Water Eng Sci*, **32,** 1978, 495–508.

JACKSON, M. C., M.Sc.; Sixty years of snow depths in Birmingham. *Weather*, **33,** 1978, 32–34.

JACKSON, M. C., M.Sc.; Snow cover in Great Britain. *Weather*, **33,** 1978, 299–309.

JAMES, P. K., B.A., D.Phil., BROWNING, K. A., Ph.D., D.I.C., F.R.S., GUNAWARDANA, R. and EDWARDS, J. A.; A case of line convection observed by radar using a high resolution colour display. *Weather*, **33,** 1978, 212–214.

JONES, M. V., M.Sc. and BALLENTINE, J.; A test of data acquisition and processing for FGGE. *Meteorol Mag*, **107,** 1978, 233–242.

KERLEY, M. J., FOOT, J. S., Ph.D. and SANDS, K. J. T.; The acquisition of meteorological data of relevance to the offshore industry. London, Institution of Electrical Engineers, Institution of Electronic and Radio Engineers, Ocean International 1978, Technical Session J, 1978, 53–56.

LEWIS, R. P. W., M.A., M.Sc.; The 'exploration' exhibition at the Science Museum. *Meteorol Mag*, **107,** 1978, 147–149.

LEWIS, R. P. W., M.A., M.Sc.; The Meteorological Office badge. *Meteorol Mag*, **107,** 1978, 338–339.

LORENC, A. C., B.A.; Results of observing systems simulation experiments for the First GARP Global Experiment. ICSU/WMO, GARP Working Group on Numerical Experimentation, Report No. 10, 1975, 37–68.

LUNNON, R. W., B.Sc.; Report on the summer school in satellite meteorology held in Alpbach, Austria from 3 to 12 August 1977. *Meteorol Mag*, **107,** 1978, 62–66.

MCGINNIGLE, J. B., *in* CAMPION, D. G., BETTANY, B. W., MCGINNIGLE, J. B. and TAYLOR, L. R.; The distribution and migration of *Spodoptera littoralis* (Boisduval) (Lepidoptera: Noctuidae), in relation to meteorology in Cyprus, interpreted from maps of pheromone trap samples. *Bull Entomol Res*, **67,** 1977, 501–522.

MCKAY, W., *in* COOK, N. J., COULSON, B. H. and MCKAY, W.; Wind conditions around the Rock of Gibraltar. *J Ind Aerodynam, Amsterdam*, **2,** 1977, 289–309.

MASON, B. J., C.B., D.Sc., F.R.S.; The future development of the Meteorological Office. *Meteorol Mag*, **107,** 1978, 129–140.

MASON, B. J., C.B., D.Sc., F.R.S.; Physics of a raindrop. London, Institute of Physics, *Phys Bull*, **29,** 1978, 364–369.

MASON, B. J., C.B., D.Sc., F.R.S.; The physics of a raindrop. *Phys Educ*, **13,** 1978, 414–419.

MASON, B. J., C.B., D.Sc., F.R.S.; Recent advances in the numerical prediction of weather and climate. *Proc R Soc*, A, **363,** 1978, 297–333.

MASON, B. J., C.B., D.Sc., F.R.S.; The world climate programme. *Nature, London*, **276,** 1978, 327–328.

MASON, B. J., C.B., D.Sc., F.R.S., *in* CHOULARTON, T. W., LATHAM, J. and MASON, B. J.; A possible mechanism of ice splinter production during riming. *Nature, London*, **274,** 1978, 791–792.

MASON, P. J., Ph.D.; The influence of topography on pollution dispersal. Geneva, World Meteorological Organization. Papers presented at the WMO Symposium on boundary layer physics applied to specific problems of air pollution, Norrköping, 19–23 June 1978, 249–256.

MASON, P. J., Ph.D. and SYKES, R. I., B.A.; A Cartesian model of boundary layer flow over topography. *J Comput Phys, New York*, **28,** 1978, 198–210.

MASON, P. J., Ph.D. and SYKES, R. I., B.A.; On the interaction of topography and Ekman layer pumping in a stratified atmosphere. *Q J R Meteorol Soc*, **104**, 1978, 475–490.

MILES, M. K., M.Sc., A.R.C.S., D.I.C.; Predicting temperature trend in the Northern Hemisphere to the year 2000. *Nature, London*, **276**, 1978, 356–359.

MILES, M. K., M.Sc., A.R.C.S., D.I.C. and GILDERSLEEVES, P. B.; A statistical study of the likely influence of some causative factors on the temperature changes since 1665. *Meteorol Mag*, **107**, 1978, 193–204.

MURGATROYD, R. J., O.B.E., Ph.D., C.Eng., M.I.E.E.; Modelage stratosphérique. Quelques developpements recents. *Météorologie, Paris*, 6e Série, 1977, No 12, 69–81.

NICHOLLS, S., B.Sc.; Measurements of turbulence by an instrumented aircraft in a convective boundary layer over the sea. *Q J R Meteorol Soc*, **104**, 1978, 653–676.

OGDEN, R. J., B.Sc.; Metmen keep a weather eye on offshore work. *Pet Rev*, July 1978, 42–44.

OLIVER, M. J. and CLULEY, A. P., Ph.D.; A systematic error in the measurement of frost point using a Meteorological Office Mk 3 hygrometer. *Q J R Meteorol Soc*, **104**, 1978, 503–509.

O'NEILL, A., B.A., and NEWSON, R. L., B.A.; Studies of stratospheric sudden warmings simulated by a general circulation model of the atmosphere. IAMAP, Commission on Meteorology of the Upper Atmosphere, Collection of Extended Summaries of Contributions Presented at Joint Assembly, Seattle, Washington, CMUA Sessions IAGA/IAMAP, 22 August–3 September 1977. Boulder, Col., 1977, 50-1–50-6.

PARKER, J., B.Sc.; Meteorological Office participation in Prestel—the Post Office viewdata system. *Meteorol Mag*, **107**, 1978, 249–254.

PETTIFER, R. E. W., Ph.D.; A brief introduction to the United Kingdom Mark 3 radiosonde system. London, Meteorological Office, 1978.

PONTING, J. F., M.Sc.; Computer processing of satellite image data. *Meteorol Mag*, **107**, 1978, 272–277.

POTHECARY, I. J. W., B.Sc., M.Inst.P.; Grusswort [to Hans Baumgärtner]. Porz-Wahn, Amt Wehrgeophysik, *Fach Mitt* Nr 187, 1978, xi.

REES, P. R., B.Sc., *in* BERTIN, F., TESTUD, J., KERSLEY, L. and REES, P. R.; The meteorological jet stream as a source of medium scale gravity waves in the thermosphere: an experimental study. *J Atmos Terr Phys*, **40**, 1978, 1161–1183.

ROWLES, K.; A guide to satellite picture analysis. *Meteorol Mag*, **107**, 1978, 205–209.

ROWNTREE, P. R., Ph.D., *in* PANDOLFO J. and ROWNTREE, P. R.; Large-scale numerical modeling. Boulder, Col., National Center for Atmospheric Research, Report of the U.S. GATE Central Program Workshop, Boulder, Col., 25 July–12 August 1977, Boulder, 1977.

ROWNTREE, P. R., Ph.D. and WALKER, JULIA M. [JULIA], B.Sc.; The effect of doubling the CO_2 concentration on radiative-convective equilibrium. International Institute for Applied Systems Analysis, IIASA Proceedings Series, Environment, Vol. 1, Oxford, 1978, 181–191.

ROY, MARJORY G., M.Sc.; Weather forecasting requirements for hay and silage-making. European Grassland Federation, 7th General Meeting, Gent, 1978.

ROY, MARJORY G., M.Sc. and HOUGH, M. N., Ph.D.; Effects of weather and climate on modern British farming. *J R Agric Soc Engl*, **139**, 1978, 43–53.

ROY, MARJORY G., M.Sc., STARR, J. R., Ph.D., D.I.C. and HOUGH, M. N., Ph.D.; Some agricultural effects of the drought of 1975–76 in the United Kingdom. *Weather*, **33,** 1978, 64–74.

RYDER, P., Ph.D.; The role of meteorology in helicopter icing problems. *Meteorol Mag*, **107,** 1978, 140–147.

SHAW, D. B., B.Sc.; Meteorology over the tropical oceans. *Nature, London*, **276,** 1978, 445–446.

SHEARMAN, R. J., B.Sc.; The speed and direction of movement of storm rainfall patterns with reference to urban storm sewer design. *Bull Sci Hydrol*, **22,** 1977, 421–431.

SHONE, K. B.; The Heatree storm of 27 June 1976. *Weather*, **33,** 1978, 52–54.

SHONE, K. B.; A notable steady rainfall over north Cornwall. *Weather*, **33,** 1978, 8–11.

SMITH, F. B., Ph.D. and CARSON, D. J., Ph.D.; Some thoughts on the specification of the boundary-layer relevant to numerical modelling. *Boundary-Layer Meteorol, Dordrecht*, **12,** 1977, 307–330.

SMITH, S. G., B.Sc.; Variability with time of poor visibility beside a motorway. *Meteorol Mag*, **107,** 1978, 289–304.

SPACKMAN, E. A., M.Sc.; The compatibility and performance of radiosonde measurements of geopotential height in the lower stratosphere for 1975–76. *Tech Note Wld Meteorol Org, Geneva*, No. 163, Part II, 1978, 27–103.

STEWART, J. B., B.Sc., Ph.D., D.I.C., *in* GASH, J. H. C., OLIVER, H. R., SHUTTLEWORTH, W. J. and STEWART, J. B.; Evaporation from forests. *J Inst Water Eng Sci*, **32,** 1978, 104–110.

STEWART, K. H., Ph.D., D.I.C.; The importance of Meteosat for meteorology. *Meteorol Mag*, **107,** 1978, 159–164.

STEWART, K. H., Ph.D., D.I.C.; The significance of Meteosat for meteorology. *Bull Eur Space Agency*, 1977, No. 11, 6–10.

SUGGITT, R. T., B.Sc.; A method for the production of accoustic forecasts using a digital computer. *Meteorol Mag*, **107,** 1978, 374–383.

TUCK, A. F., Ph.D.; Changes in the ozone layer. London, Institute of Physics, *Phys Bull*, **29,** 1978, 168–171.

TUCK, A. F., Ph.D.; Covariance and averaging of gases in 1, 2 and 3-dimensional atmospheric models. Geneva, World Meteorological Organization. Papers presented at the WMO Symposium on the geophysical aspects and consequences of changes in the composition of the stratosphere, Toronto, 26–30 June 1978, 247–254.

TYLDESLEY, J. B., B.A.; A method of evaluating the effect of temperature on an organism when the response is non-linear. *Agric Meteorol, Amsterdam*, **19,** 1978, 137–153.

WALES-SMITH, B. G.; MORECS—a new meteorological service for the water industry. *Water, London*, 1978, No. 12, 10–11.

WALLER, M. G.; The relationship between visibility and surface wind at Gütersloh in winter with particular reference to smoke pollution. *Meteorol Mag*, **107,** 1978, 278–287.

WELLER, M. J. and COLLISON, P., *in* RATCLIFFE, R. A. S., WELLER, M. J. and COLLISON, P.; Variability in the frequency of unusual weather over approximately the last century. *Q J R Meteorol Soc*, **104,** 1978, 243–255.

WHITE, G. A.; Meteorological services to aid navigation. *Mar Obs*, **48,** 1978, 123–126.

WHITE, G. A.; Recommissioning of the OWS 'Weather Adviser' under a new name. *Mar Obs*, **47,** 1977, 127–128.

WHITE, P. [W.], Ph.D.; Mesoscale modelling. European Centre for Medium-range Weather Forecasts, Seminars 1978, 1978, 17–55.

WILEY, R. L., Ph.D., *in* WOODS, J. D., WILEY, R. L. and BRISCOE, M. G.; Vertical circulation at fronts in the upper ocean. ANGEL, M. A voyage of discovery. Oxford, Pergamon Press, 1977, 253–275.

APPENDIX II

A SELECTION OF LECTURES AND BROADCASTS GIVEN BY MEMBERS OF STAFF

ADAMS, R. J., Ph.D.

Irrigation planning. *Royal Meteorological Society Discussion Meeting on 'Agricultural Meteorology', Imperial College, London.* 18 January.

Weather and the soil. *Royal Agricultural Society, Stoneleigh, War.* 14 February.

Theoretical aspects of shelter design. *Institute of Agricultural Engineers, Silsoe, Beds.* 6 March.

Climate and drainage. *Regional Conference of ADAS Land Drainage Service, Shuttleworth, near Biggleswade, Beds.* 11 April.

ALLARDICE, J.

Participation in program on the work of Lerwick Observatory and Forecast Office, BBC Radio Shetland. 13 December.

ALLEN, J. J.

Meteorology for yachtsmen. *Series of lectures to Royal Yachting Association Yachtmasters' Course, Fleet, Hants.* Winter Term.

ATKINS, MARGARET J., B.Sc.

The use of satellite sounding data in routine weather forecasting. *COSPAR Symposium on Remote Sounding of the Atmosphere from Space, Innsbruck.* 1 June.

AXFORD, D. N., Ph.D., C.Eng., M.I.E.E.

Operation of meteorological sensors in the offshore environment. *International Conference on Meteorology and Oceanography applied to the Engineering, Installation and Operation of Offshore Structures, The Hague.* 31 October.

BAYLISS, J. M.

Weather forecasting and ship routeing. *The Nautical Institute, Avon Branch, Bristol.* 21 November.

BECKLEY, R. M. and MARSHALL, G. A.

A career in meteorology. *Granada TV program 'What's New'.* 26 May.

BEST, K. E.

The St Swithun legend and the weather of summer 1978. *Interview on BBC Radio Solent, Southampton.* 13 August.

Meteorological Office services. *Dorset County Council Divisional Surveyors, Dorchester.* 28 September.

BEST, K. E. and SHORNEY, P. W.

Weather ships and Meteorological Office offshore services. *BBC Radio Solent, Southampton.* 22 November.

BEST, K. E., FISH, M. J., GILES, W. G., SCOTT, J. and WATSON, BARBARA

A review of the weather in 1977. *BBC TV program 'We had Rain—We had Sun'.* 1 January.

BEST, K. E., FISH, M. J., GILES, W. G., MCCASKILL, J. R., SCOTT, J. and WATSON, BARBARA

That was the weather that was (survey of weather in 1978). *BBC TV.* 31 December.

BIBB, M.

Bank Holiday weather. *Interview on Thames TV program 'Thames at Six'.* 26 May.

BLACKALL, R. M., B.Sc.

Forecasting mountain weather. *North London Mountain Leaders' Association, London.* 28 February.

Lectures and instruction at the Royal Meteorological Society Field Study Course on 'Mountain Weather', Betws-y-Coed, Gwynedd. 26 July–2 August.

More on forecasting mountain weather. *North London Mountain Leaders' Association, London.* 30 November.

BRADBURY, T. A. M.
Meteorological conditions favourable for long closed-circuit soaring flights over England. *16th OSTIV Congress, Châteauroux, France.* 20–29 July.

BRITTAIN, O. W.
Sea breezes. *Royal Meteorological Society Discussion Meeting on 'Local Climates', University College, London.* 14 October.

BROWN, R., B.Sc.
The physics of radiation fog. *Thames Valley Physics Society, University of Reading.* 1 November.

CARPENTER, K. M., Ph.D.
A non-hydrostatic mesoscale model.
Naval Postgraduate School, Monterey, Calif. 8 May.
National Center for Atmospheric Research, Boulder, Col. 11 May.

CARSON, D. J., Ph.D.
The representation of air–sea interaction processes in atmospheric circulation models. *Royal Meteorological Society Summer Meeting, University College, Swansea.* 21 July.
The problems of parametrizing air–sea interaction processes in atmospheric circulation models. *Seminar, University of Reading.* 24 November.

CLARK, G. V.
Current weather in north-east England. *Recorded interview, Radio Metropolitan, Newcastle upon Tyne.* 17 August.

CLOUGH, S. A., Ph.D.
Studies of the natural and perturbed stratosphere in a simplified 2-D model. *CEC Co-ordinated Meeting on European Research on the Ozone Shield Depletion Problem, Study Group III, Brussels.* 19 October.

COCHRANE, J.
Some meteorological aspects of pest and disease control. *Crop Protection Course, Reading University, and at Cambridge.* 18 May and 21 July.

COLLIER, C. G., B.Sc., A.R.C.S.
Radar measurement of rainfall. *School of Maritime Studies, Plymouth Polytechnic.* 27 April.

CULLEN, M. J. P., Ph.D.
Numerical methods in weather forecasting.
IMA Conference on Numerical Methods in Applied Fluid Dynamics, University of Reading. 6 January.
Atomic Weapons Research Establishment, Aldermaston. 11 April.
Finite element methods in large-scale weather forecasting. *Mathematics of Finite Elements and Applications, Brunel University, Uxbridge.* 20 April.
Intercomparison of forecasts from hemispheric models. *Royal Meteorological Society Specialist Group on Dynamical Problems, University of Reading.* 18 May.
Numerical methods in weather forecasting. *Institute of Oceanographic Sciences, Bidston.* 11 October.
The relation between finite difference and finite element solutions of evolutionary problems. *Liverpool University.* 15 November.

DAVIES, T. M., B.Sc. and MORRIS, R. M., B.Sc.
The weather. *Interview on BBC Radio Wales, Cardiff.* 6 March.

DEEKS, P. H. G.
Wave and swell forecasting in the North Sea.
Royal Meteorological Society, Manchester Centre. 7 March.
Royal Meteorological Society, East Midlands Centre, University of Nottingham. 14 November.

DENT, L., B.Sc.

Forecasting methods. *Six lectures to the M.Sc. course, Department of Geophysics, University of Reading.* March–May.

Aviation meteorology. *Two lectures to the course for aircraft accident investigators, Cranfield Institute of Technology, Beds.* 5 and 6 June.

EMERY, P. F.

The weather. *Phone-in program, Radio Metropolitan, Newcastle upon Tyne.* 3 February.

The radiosonde. *Talk broadcast on BBC Radio Carlisle.* 1 March.

The weather of summer 1978. *Recorded interview, BBC Radio Cleveland.* 4 August.

The wet weather in early August. *Recorded interviews, Radio Metropolitan and BBC Radio Tees, and live broadcast on BBC TV (North).* 8 August.

Forecasting services for Cumbria. *Recorded interview, BBC Radio Carlisle.* 11 September.

Newcastle Weather Centre. *BBC Radio Newcastle.* 20 December.

FISH, M. J.

Weather. *Queen Mary College Geographical Society, London.* 24 February.

The weather in summer 1978. *Interview on BBC TV (Leeds) program 'Look North'.* 17 August.

FOLLAND, C. K., B.Sc., M.Inst.P.

Aspects of rainfall climatology in the United Kingdom. *Royal Meteorological Society Specialist Group on British Climatology, University of Hull.* 6 January.

Rain-gauge rationalization. *Meeting of Regional Hydrologists, Bristol.* 15 March.

Recent and planned studies in the Meteorological Office with an application to urban drainage design. *International Conference on Urban Storm Drainage, Southampton.* 11 April.

Meteorological aspects of drainage design. *PTRC Drainage Course, London.* 10 May.

Storm movement. *Institution of Civil Engineers, Hydrological Group Meeting, London.* 15 May.

Rain-gauging. *Symposium on Rainfall for Water Authority Staff, Meteorological Office College, Shinfield Park.* 19 September.

FOORD, H. V.

Public Services in the Meteorological Office. *Queen's University Air Squadron, Belfast.* 4–5 May.

FOOT, J. S., Ph.D.

Specifying the characteristics of an instrument. *Royal Meteorological Society Discussion Meeting on 'Instruments for Amateur Observers', University College, London.* 6 May.

Sensor developments in the United Kingdom. *Two informal seminars, Geophysical Research Laboratories, Boston, Mass.* 25 and 27 July.

The use of laser cloud-base recorders for the Meteorological Office. *Conference on Atmospheric Sensing with Lasers, Society of Chemical Industry, London.* 9 October.

FOOT, J. S., Ph.D., KERLEY, M. J. and SANDS, K. J. T.

The acquisition of meteorological data of relevance to the offshore industry. *Oceanology International 1978 Conference, Brighton.* 9 March.

FRANCIS, P. E., Ph.D.

Meteorology and agriculture. *Department of Meteorology, University of Edinburgh.* 2 February.

Services to agriculture. *Northern Ireland Department of Agriculture, Belfast.* 14 September.

GADD, A. J., Ph.D.

Computers and the weather. *Department of Computing and Control, Imperial College, London.* 25 January.

The use of computers in weather forecasting. *British Computer Society, North-west London Branch.* 7 March.

GEORGE, D. J.

Weather for mountaineers. *Royal Meteorological Society/Sports Council Field Study Course, Capel Curig, Gwynedd.* 1–8 April.

GEORGE, J.

The local weather measurement—an aid to improved control. *British Gas School of Engineering, Newcastle upon Tyne.* 28 September.

GIBBS, J. I., D.Phil.

Lidar systems for stratospheric aerosols and cirrus cloud investigation. *Conference on Atmospheric Sensing with Lasers, Society of Chemical Industry, London.* 9 October.

GILCHRIST, A., M.A.

General circulation investigations and climate modelling in the Meteorological Office. *Mainz University.* 26 January.

Simulation of the climatic effects of massive heat releases into the atmosphere at energy parks. *Jouy-en-Josas, Paris.* 20 October.

GILES, W. G.

Weather influences on the *Amico Cadiz* oil slick. *Interview on BBC TV program 'Nationwide'.* 20 March.

Weather in summer 1978 in the UK. *Talk on BBC World Service.* 9 August.

The weather. *Phone-in program 'Plymouth Sound' on Plymouth Commercial Radio.* 15 August.

GILES, W. G. and SCOTT, J.

The farming forecast. *Participation in film shown at Royal Agricultural Show, Stoneleigh, War.* 3–6 July.

GOLDING, B. W., B.Sc.

Numerical guidance on forecasting wind and waves for the Continental Shelf. *Joint Meeting of Royal Meteorological Society/Society for Underwater Technology, London.* 22 February.

A depth dependent wave model for operational forecasting. *Seminar at Institute of Oceanographic Sciences, Taunton.* 16 May.

GOLDSMITH, P., M.A.

Weather modification—intentional. *University of Reading.* 13 March.

Inadvertant weather modification. *University of Reading.* 16 March.

The 5-year forecast. *Contribution to documentary on BBC Radio* 4. 27 July.

Man's possible influence on climate. *Contribution to discussion program 'Your World', BBC Overseas Service.* 9 August.

GRANT, D. R., B.Sc.

Aviation accident prevention investigative techniques. *A course of lectures at Royal Institute of Technology, Institute of Aviation Safety, Stockholm.* 10–14 April.

GRAYSTONE, P., B.A.

Work in progress in the UK Meteorological Office. *CEC Co-ordinated Meeting on European Research on the Ozone Shield Depletion Problem. Study Group III, Brussels.* 15 February.

Studies of atmospheric chemistry using a hemispheric model. *WMO Symposium on the Geophysical Aspects and Consequences of Changes in the Composition of the Stratosphere, Toronto.* 29 June.

GREGSON, J.

Meteorology for yachtsmen. *Series of lectures to Royal Yachting Association Yachtmasters' Course, Fleet, Hants.* Spring Term.

GRINDLEY, J., B.A.

Rainfall advice. *Symposium on Rainfall for Water Authority Staff, Meteorological Office College, Shinfield Park.* 19 September.

HAYES, F. R., B.A.

The application of numerical models to long-range forecasting. *The Institute of British Geographers, Hull.* 5 and 6 June.

HIDE, R., Sc.D., F.R.S.

Experiments with rotating fluids.

Institute for Atmospheric Physics, Moscow. 9 June

Computing Centre, Novosibirsk. 20 June.

Institute of Oceanology, Leningrad. 23 June.

Max-Planck Institut für Meteorologie, Hamburg. 20 September.

How to create the fluid metallic core of a planet from external magnetic observations.

Mathematics Institute, University of Essex. 24 February.

Department of Meteorology, University of Reading. 10 March.

Second United Kingdom Geophysical Assembly, Liverpool University. 11 April.

Institute of Physics of the Earth, Moscow. 15 June.

Institute for Research on Earth's Magnetism, Ionosphere and Wave Propagation, Moscow. 16 June.

HOPKINS, J. S., B.Sc., A.R.C.S.

Weather in Scotland. *BBC TV (Scotland) and BBC Radio (Scotland).* 15 February, 10 July and 12 October.

Applied climatology. *University of Glasgow.* 23 February.

Cloud, rain, snow, and meteorological information for planning. *Lectures at Royal Meteorological Society Course on 'Meteorology for Civil Engineering and Building', University of Reading.* 13 April.

Scotland's climate. *Symposium on Man and Landscape, University of Stirling.* 18 November.

HOUGHTON, D. M., M.Sc., D.I.C.

Commercial applications of long-range forecasts. *A presentation to British Petroleum, Britannic House, London.* 11 January.

Recent severe weather in relation to our climate. *Recorded interview for 'Good Morning Wales', BBC Radio 4 (Wales).* 6 March.

Two seminars: (1) Current progress in long-range forecasting, (2) Forcing factors relevant to climatic studies. *University of East Anglia.* 14 March.

Climate and climatic change. *Recorded interview with Dr Reiger, Political Science Editor, North German Radio, for a series of documentary programs.* 17 March.

Climate and climatic change. *Recorded interview for BBC Radio 4.* 5 June.

Recorded interview for BBC TV News in connection with H.M. The Queen's visit to Bracknell. 14 July.

Recent wet weather. *Interview on the Jimmy Young program, BBC Radio 2.* 11 August.

Long-range forecasting—climatology or prediction? *International Conference on Meteorology and Oceanography applied to the Engineering, Installation and Operation of Offshore Structures, The Hague.* 1 November.

Long-range forecasting—science or sorcery? *University College, Swansea.* 16 November.

Long-range weather forecasting. *Ascot Round Table.* 23 November.

Weather forecasting. *Royal Yachting Association Race Management weekend seminar, Hayling Island, Hants.* 25 November.

HUNT, R. D., B.Sc.

The weather. *Phone-in program on Radio 210 (Thames Valley Broadcasting Ltd).* 11 August.

Weather science and weather forecasting. *Royal Meteorological Society Field Study Course, Williton, near Taunton, Somerset.* 24–30 August.

The weather. *Phone-in program, BBC Radio Oxford.* 29 November.

INGHAM, B.

Agricultural meteorology. *Gloucester College of Agriculture.* 6 June.

JAMES, I. N., Ph.D.

Side-band instability of baroclinic waves.
University of Reading. 20 January.
Atmospheric Physics Group, Imperial College, London. 9 February.

Non-linear interactions of baroclinic waves. *20th British Theoretical Mechanics Colloquium, Sheffield University.* 12 April.

Combined laboratory and numerical study of baroclinic waves. *American Meteorological Society, Second Meeting on 'Atmospheric and Oceanic Waves and Stability', Boston, Mass.* 24 October.

Recent theoretical and experimental studies of baroclinic waves. *Culham Laboratory, Appleford, Oxon.* 22 November.

JOHNSON, G. C.

Mountain weather. *Talk on BBC Radio London.* 6 July.

JONAS, P. R., Ph.D.

Laboratory analogues of atmospheric flows. *Institute of Physics, Guildford.* 10 May.

Geostrophic turbulence in a rotating differentially heated annulus. *European Mechanics Colloquium No.* 105, *Grenoble, France.* 8 September.

Recent combined laboratory and numerical studies of baroclinic waves in an annulus. *European Mechanics Colloquium No.* 106, *Grenoble, France.* 13 September.

JONES, D. E., M.Sc., D.I.C., A.R.C.S.

Work of the Central Forecasting Office. *Recorded radio interview for BBC Radio (Wales).* 6 March.

KING, J. C., B.Sc.

An experimental study of baroclinic wave interactions in a two-layer rotating fluid. *Second United Kingdom Geophysical Assembly, Liverpool University.* 11 April.

Non-linear baroclinic wave interactions in a two-layer rotating fluid. *20th British Theoretical Mechanics Colloquium, Sheffield University.* 12 April.

Experimental studies of baroclinic wave interactions. *Fifth Meeting of the European Geophysical Society, Strasbourg, France.* 29 August.

LOVE, J. P.

Forecasting for the farmer. *Ednam Young Farmers Club, Kelso.* 18 October.

MCCASKILL, J. R.

Weather in Manchester, summer 1978. *Interview on BBC TV program 'Look North'.* 24 July.

MCKELLAR, H. A.

Meteorological Office services. *Bridgeton (Glasgow) Business Club.* 12 January.

The January snowfall in northern Scotland. *Interview on BBC TV and BBC Radio 4 program 'P.M.'.* 30 January.

A plain man's guide to weather. *Talk on Radio Clyde.* 2 March.

The requirements of the weather forecast supplier. *Royal Society of Edinburgh/Royal Meteorological Society, Scottish Centre, Symposium on Scottish Mountain Weather, University of Edinburgh.* 17 March.

Scottish mountain weather. *Recorded interview for BBC Radio (Scotland).* 17 March.

Rainfall forecasting—the present position in Scotland. *Symposium of River Purification Boards and Regional Councils, Edinburgh.* 17 November.

MASON, B. J., C.B., D.Sc., F.R.S.

Recent progress in the numerical prediction of weather and climate.
Culham Laboratory, Appleford, Oxon. 3 March.
Review Lecture, Royal Society, London. 27 April.

Recent developments in the computer modelling of climate. *University of Berne.* 5 June.
Nature and man-made climatic changes—the results of recent numerical experiments. *XVII General Assembly of ICSU, Athens.* 27 September.
Precision and accuracy of weather forecasts. *Chelsea College.* 19 October.
Numerical modelling of climate. *The Archimedeans, Cambridge University.* 17 November.

MASON, P. J., Ph.D.

Numerical studies of pollutant transport near three-dimensional topography. *WMO Symposium on Boundary-layer Physics Applied to Specific Problems of Air Pollution, Norrköping, Sweden.* 21 June.
Two lectures: (1) Flow over hills—a review of a research program, (2) Numerical studies of flow over surface-mounted obstacles. *Danish Atomic Energy Department, Risø, Denmark.* 20–26 November.

MASON, P. J., Ph.D. and SYKES, R. I., B.Sc.

Three-dimensional separation around a surface-mounted obstacle at moderate Reynolds numbers. *20th British Theoretical Mechanics Colloquium, Sheffield University.* 11 April.
A review of Met O 14's work on flow over topography. *Geophysical Fluid Dynamics Laboratory, Princeton University, N.J.* 1 May. *National Center for Atmospheric Research, Boulder, Col.* 9 May.
On the interaction of topography and Ekman boundary-layer pumping in a stratified atmosphere. *Royal Meteorological Society, Imperial College, London.* 15 November.

MILES, M. K., M.Sc., A.R.C.S., D.I.C.

Temperature and rainfall of the British Isles in relation to some circulation indices. *Royal Meteorological Society Specialist Group on British Climatology, University of Hull.* 6 January.
Climate prediction to AD 2000. *Royal Aeronautical Society, Midlands Branch.* 16 February.

MILLER, D. E., B.A.

Applications of satellite techniques to operational meteorology. *Nottingham Physics Centre, University of Nottingham.* 23 February.
Operational temperature sounding of the stratosphere. *Discussion Meeting on 'The Middle Atmosphere as Observed by Balloons, Rockets and Satellites', Royal Society, London.* 12 December.

MITCHELL, J. F. B., Ph.D.

Weather forecasting. *Science Society, Kingston Polytechnic.* 9 March.

MORRIS, R. M., B.Sc.

Forecasting wind and waves for the offshore industry. *Institute of Petroleum, London.* 11 January.
Weather forecasting for the offshore industry. *Joint Meeting of Royal Meteorological Society/Society for Underwater Technology, London.* 22 February.
The weather. *Talk on BBC Radio (Wales), Cardiff.* 6 March.
The weather. *Phone-in program on BBC Radio London.* 10 May.
The weather in summer 1978. *Talk on British Forces Broadcasting Service.* 24 July.
Thunderstorms. *Talk on BBC Radio 4 program 'Women's Hour'.* 24 July.
The autumn heatwave. *Interview on ITV News.* 12 October.

MURGATROYD, R. J., O.B.E., Ph.D., C.Eng., M.I.E.E.

The state of the art of models and computer codes on stratospheric circulation phenomena with associated behaviour of chemical components. *Joint Research Council, Ispra, Italy.* 26 January.

NICHOLASS, C. A., B.Sc.

Rain-gauge network rationalization. *Symposium on Rainfall for Water Authority Staff, Meteorlogical Office College, Shinfield Park.* 19 September.

OGDEN, R. J., B.Sc.

Applications of meteorology to civil engineering. *Polytechnic of the South Bank, London.* 18 January.

Weather and climate, surface wind, and working overseas. *Lectures at Royal Meteorological Society Course on 'Meteorology for Civil Engineering and Building', University of Reading.* 13–14 April.

Public services. *Institute of Personnel Management, Thames Valley Branch.* 15 November.

O'NEILL, A., B.A.

A dynamical study of a stratospheric sudden warming simulated by a general circulation model of the troposphere and stratosphere.
Free University of Berlin. 6 February.
Royal Meteorological Society Specialist Group on Dynamical Problems, Meteorological Office College, Shinfield Park. 16 February.

A dynamical study of the major warming of 1976–1977. *Free University of Berlin.* 9 February.

PAGE, R. L.

The use of infra-red radiation for cloud observation from weather satellites. *Physics at Work Exhibition, University of Surrey, Guildford.* 4, 5 and 6 July.

Mountain weather. *Royal Meteorological Society Field Study Course, Betws-y-Coed, Gwynedd.* 26 July–2 August.

PAINTING, D. J., B.Sc.

Establishment of a complete marine and postal station archive for a fully coherent data base. *International Conference on Meteorology and Oceanography applied to the Engineering, Installation and Operation of Offshore Structures, The Hague.* 1 November.

PARTINGTON, S. J. G.

Summer weather in Northern Ireland. *BBC TV (Northern Ireland).* 4 July.

PEPPERDINE, E. C.

The weather. *Bassetlaw Astronomical Society, Notts.* 14 March.

PETTIFER, R. E. W., Ph.D.

Review of meteorological applications of lasers. *Conference on Atmospheric Sensing with Lasers, Society of Chemical Industry, London.* 9 October.

Meteorological data acquisition systems for operations on the Continental Shelf. *International Conference on Meteorology and Oceanography applied to the Engineering, Installation and Operation of Offshore Structures, The Hague.* 1 November.

PETTIFER, R. E. W., Ph.D. and AXFORD, D. N., Ph.D., C.Eng., M.I.E.E.

The meteorological contribution to COST 43 by the United Kingdom—a progress report. *European Conference on COST 43, Lisbon.* 4–6 December.

PHILLIPS, A.

Weather routeing. *The Nautical Institute, Avon Branch, Bristol.* 21 November.

PHILLIPS, B.

The work of the Meteorological Office. *The New Society, Camberley, Surrey.* 13 June.

PICK, D. R., D.Phil.

The UK Meteorological Office Stratospheric Sounding Unit, its design and products. *Symposium on Remote Sensing of the Atmosphere from Space, 21st COSPAR Meeting, Innsbruck.* 3 June.

RACKLIFF, P. G.

Meteorological organization and planning for nuclear fall-out exercises. *Home Defence College, Easingwold, N. Yorks.* 6 January.

Production and use of effective downwind messages. *Scientific Advisers' Course, Civil Emergency Planning Unit, Cheshire County Council, Hartford College.* 18 March.

RIDDAWAY, R. W., Ph.D.

Use of computers in weather forecasting. *Part of a Complementary Studies Course (Computers and Society), University of Aston in Birmingham.* 17 January.

How computers are used in weather forecasting. *South of England ICL Computer Users' Association, Shepperton.* 17 October.

ROWNTREE, P. R., Ph.D.

The effects of doubling the carbon dioxide concentration on radiative-convective equilibrium (text by P. R. Rowntree and Mrs J. M. Slingo). *WMO/IIASA Workshop on Carbon Dioxide, Climate and Society, Laxenburg, Austria.* 23 February.

Statistical assessments of sea temperature anomaly experiments. *JOC Study Conference on Climate Models, Washington, D.C.* 5 April.

Numerical prediction and simulation of the tropical atmosphere. *Royal Society/Royal Meteorological Society/American Meteorological Society/Deutsche Meteorologische Gesellschaft Conference on Meteorology over the Tropical Oceans, London.* 22 August.

ROY, MARJORY G., M.Sc.

The agricultural effects of the drought of 1975–76 in the United Kingdom. *Association of British Climatologists, University of Nottingham.* 20 September.

SCOTT, J.

Weather forecasting. *Royal Meteorological Society Course on 'Meteorology for Civil Engineering and Building', University of Reading.* 13–14 April.

The weather. *Institution of Electrical Engineers, London.* 18 May.

Farming weather. *Talk on BBC Radio 4 Farming Program.* 9 July.

The weather in summer 1978. *Interview on BBC TV program 'Midlands Today'.* 3 August.

Participation in educational film 'Mind your Language', ATV. 15–16 November.

SLINGO, JULIA M., B.Sc.

The importance of interactive cloud and radiation in a numerical model of the tropics. *Royal Society/Royal Meteorological Society/American Meteorological Society/Deutsche Meteorologische Gesellschaft Conference on Meteorology over the Tropical Oceans, London.* 24 August.

Interactive cloud and radiation in a numerical model. *Royal Meteorological Society Specialist Group on Dynamical Problems, Meteorological Office College, Shinfield Park.* 26 October.

SMITH, F. B., Ph.D.

The dispersion of pollutants in the atmosphere. *Six lectures to the M.Sc. course on Radiation and Environmental Protection, University of Surrey, Guildford.* 2–16 February.

The application of field-experimental data to the parametrization of the dispersal of plumes from ground level and elevated sources. *Institute of Mathematics and its Applications, London.* 12 September.

Application of data from field experiments to the prediction of the dispersion of pollutants in the lower atmosphere. *Royal Meteorological Society, Imperial College, London.* 18 October.

SPACKMAN, E. A., M.Sc.

An objective approach to the division of the UK into climatic regions. *Royal Meteorological Society Specialist Group on British Climatology, University of Hull.* 6 January.

SPALDING, T. R., B.Sc.

Mountain weather. *Course of lectures to the Royal Meteorological Society Field Study Course, Betws-y-Coed, Gwynedd.* 26 July–2 August.

SPARKS, W. R., B.Sc.

Aspects of agricultural meteorology.

Farmers' Discussion Group, Mere, Wilts. 2 February.

New Entrants' Course, ADAS, Bristol. 21 October.

Starcross, Devon. 2 October.

STARR, J. R., Ph.D.
How meteorology can help profit in Kent. *Kent County Agricultural Society, Maidstone.* 18 January.
Weather and spraying. *Bicester Arable Group, Oxon.* 8 February.
Weatherwise. *West Sussex Fruit Group, Petworth.* 11 April.
Meteorological aspects of irrigation planning. *Hampshire College of Agriculture, Sparsholt.* 17 April.
Windbreaks and shelter belts. *Windbreak Workshop, MAFF, Brogdale Farm, Faversham, Kent.* 26 April.
Agricultural meteorology. *Great Shefford Young Farmers' Club, Berks.* 27 June.
Meteorology—its contribution towards solving mechanization problems. *Mechanization Advisory Officers' National Technical Conference, Cardington, Beds.* 14 November.
Windbreaks and shelter belts. *Surrey Nursingstock Discussion Group, Merrist Wood Agricultural College.* 30 November.

STEWART, J. B., Ph.D., B.Sc., D.I.C.
A model of forest transpiration and interception, using data from an automatic weather station. *SWECON/IUFRO Workshop on Energy Exchange Simulation Models, Uppsala, Sweden.* 27 September.

STEWART, K. H., Ph.D.
Uses of satellites in meteorology. *Royal Aeronautical Society, Luton and Stevenage Branch, Stevenage.* 5 December.

STRAIN, W. J.
The weather in summer 1978. *Recorded interview for BBC Radio Newcastle.* 31 August.

SYKES, R. I., B.A.
Theoretical studies of flow over topography. *Royal Holloway College, Egham.* 17 May.
Three-dimensional boundary-layer flow over surface irregularities. *Sheffield University.* 29 November.

TABONY, R. C., B.Sc.
The evidence for climatic change. *Course for ADAS staff, Meteorological Office College, Shinfield Park.* 21 March.

TANN, D. W.
Meteorological support of Home Office operations. *Home Defence Meeting, Worthing.* 4 May.

THOMPSON, N., Ph.D.
Tethered balloons in air–sea interaction. *NATO School on Instruments and Methods in Air–Sea Interaction, Ustaoset, Norway.* 26 April.

TODD, J. K.
Local weather forecasting. *Lake District National Park Wardens' Training Course, Ambleside.* 8 February.

TUCK, A. F., Ph.D.
Effects of carbon dioxide on ozone. *Clean Air Council Meeting, British Petroleum, Sunbury-on-Thames.* 10 April.

TYLDESLEY, J. B., B.A.
Irrigation planning for vegetable crops. *ADAS, Ormskirk, Lancs.* 8 February.
Weather, mechanization requirements and crop spraying. *ADAS, Durham.* 4 May.

VAUGHAN, G., B.A.
Measurements of ozone from South Uist using Petrel rockets. *Magnetosphere, Ionosphere and Solar-Terrestrial Meeting of the Royal Astronomical Society, University of Southampton.* 6 April.

WALES-SMITH, B. G.
The measurement and estimation of transpiration and evaporation. *University of East Anglia, Norwich.* 18 May.
WATERFALL, P. F.
The weather. *Nottingham Engineers' Society.* 20 March.
WATKISS, B. O.
The weather in 1978. *BBC Radio Solent.* 31 December.
WHITE, G. A.
The progress of marine meteorological services to shipping during the last ten years. *The Honourable Company of Master Mariners, London.* 22 March.
WHITE, P. W., Ph.D.
Three lectures on mesoscale modelling. *ECMWF Seminar on 'The Interpretation and Use of Large-scale Numerical Forecast Products', Meteorological Office College, Shinfield Park.* 4 and 5 September.
Mesoscale research in the UK Meteorological Office. *US Army Meso-Meteorology Advisory Panel, Las Cruces, N. Mex.* 18 September.
WHITEWAY, J. R., M.Sc.
The structure and energetic of easterly waves in a limited area tropical model (text by J. R. Whiteway and D. B. Shaw). *Royal Society/Royal Meteorological Society/American Meteorological Society/Deutsche Meteorologische Gesellschaft Conference on Meteorology over the Tropical Oceans, London.* 22 August.
WOODCOCK, A., B.Sc.
Radar rainfall. *Symposium on Rainfall for Water Authority Staff, Meteorological Office College, Shinfield Park.* 19 September.
WOODLEY, K.
Rainfall data handling. *Symposia on Rainfall for Water Authority Staff, Meteorological Office College, Shinfield Park, and Meteorological Office, Edinburgh.* 19 September and 17 October.

APPENDIX III

PUBLICATIONS

The publications prepared by the Meteorological Office are generally issued by Her Majesty's Stationery Office as official publications. Catalogues listing all the publications which may be purchased through the sales office or usual agents of Her Majesty's Stationery Office, or direct from the Meteorological Office at Bracknell, are sent free to any applicant.

The following publications have been issued:

PERIODICAL

Annual Report on the Meteorological Office 1977.

Daily Aerological Record containing information in respect of meteorological conditions in the upper air for the British Isles.

Daily Weather Report containing weather maps for the northern hemisphere, British Isles etc., and data.

Monthly Summary of the *Daily Weather Report.*

Monthly Weather Survey and Prospects, a monthly publication containing climatological data for the United Kingdom, the weather of the past month, a general survey and inference, and weather prospects for the coming month in the United Kingdom; a supplementary document, containing survey, inference and prospects only, is published in mid month.

Estimated Soil Moisture Deficit and Potential Evapotranspiration over Great Britain, a seasonal fortnightly publication providing estimates of soil moisture deficit in map form and as a tabular statement for river authority areas.

Sea Ice Charts (daily).

Monthly (coloured) *Ice Maps* (to September 1978).

Meteorological Magazine (monthly).

Monthly Weather Report (to June 1978).

Marine Observer (quarterly).

OCCASIONAL

A course in elementary meteorology, 2nd edition (1978).

Meteorology for Mariners, 3rd edition (1978).

APPENDIX IV

ACRONYMS AND ABBREVIATIONS

AAFCE	Allied Air Forces Central Europe
ACE	Allied Command Europe
ACRE	Automatic Climatological Recording Equipment
ACUCS	Advisory Committee for the Use of the Centre's Computer System
ADAS	Agricultural Development and Advisory Service
AFCENT	Allied Forces Central Europe
AGARD	Advisory Group on Aerospace Research and Development
ASDAR	Aircraft to Satellite Data Relay
ASP	Asymmetric Multiprocessing System
ASR	Altimeter Setting Region
ATOC	Airfield Tasking Operations Centres
ATWS	Automatic Telephone Weather Service
AUTOCOM	Automated Telecommunication Complex
AUTOPREP	Automatic Message Preparation Equipment
AWS	Automatic Weather Station
BAS	British Antarctic Survey
CAMFAX	Civil Aviation Meteorological Facsimile Network
CARD	Continuous Automatic Remote Display
CAS	Commission for Atmospheric Sciences (WMO)
CBS	Commission for Basic Systems (WMO)
CCITT	International Telegraph and Telephone Consultative Committee
CEC	Commission of the European Communities
CEPT	Conférence Européenne des Postes et Télécommunications
CFO	Central Forecasting Office
CIMO	Commission for Instruments and Methods of Observation
COM	Computer Output on Microfilm
CoSAMC	Commission for Special Applications of Meteorology and Climatology
COSMOS	Meteorological Office computing system
COSPAR	Committee for Space Research (ICSU)
COST	European Co-operation in Science and Technology
CPU	Central Processing Unit
CRDF	Cathode Ray Direction Finding
DALE	Digital Anemograph Logging Equipment
DB	Data Buoy
DEC	Digital Equipment Corporation
EC	Executive Committee (WMO)
ECE	Economic Commission for Europe
ECMWF	European Centre for Medium-range Weather Forecasts
ESA	European Space Agency
FGGE	First GARP Global Experiment (WMO/ICSU)
GARP	Global Atmospheric Research Program (WMO/ICSU)
GATE	GARP Atlantic Tropical Experiment (WMO/ICSU)
GDPS	Global Data Processing System (WMO)

GMT	Greenwich Mean Time
GOS	Global Observing System (WMO)
GTS	Global Telecommunication System (WMO)
IAMAP	International Association of Meteorology and Atmospheric Physics (IUGG)
IBA	Independent Broadcasting Authority
IBM	International Business Machines Ltd
ICAO	International Civil Aviation Organization
ICL	International Computers Ltd
ICSU	International Council of Scientific Unions
IEA	International Energy Agency (OECD)
IHD	International Hydrological Decade
IIASA	International Institute for Applied Systems Analysis
IMA	Institute of Mathematics and its Application
IMCO	Inter-Governmental Maritime Consultative Organization
IOS	Institute of Oceanographic Sciences
ISO	International Organization for Standardization
ITE	Institute of Terrestrial Ecology (NERC)
IUFRO	International Union of Forest Research Organizations
IUGG	International Union of Geodesy and Geophysics (ICSU)
JASIN	Joint Air–Sea Interaction Experiment (Royal Society)
JES3	Job Entry Sub-system 3
JOC	Joint GARP Organizing Committee (WMO/ICSU)
JRC	Joint Research Council
LANBY	Large Navigation Buoys
LCBR	Laser Cloud Base Recorder
LORAN	Long-range Navigation System
MAFF	Ministry of Agriculture, Fisheries and Food
MCMG	Military Committee Meteorological Group (NATO)
METAG	Meteorological Advisory Group
MIT	Massachusetts Institute of Technology
MMO	Main Meteorological Office
MOD(PE)	Ministry of Defence (Procurement Executive)
MOLFAX	Meteorological Office Land-line Facsimile Network
MONEX	Monsoon Experiment, India (GARP/ICSU)
MORECS	Meteorological Office Rainfall and Evaporation Calculation System
MOTNE	Meteorological Operational Teleprinter Network in Europe
MOWOS	Meteorological Office Weather Observing System
MRF	Meteorological Research Flight
MTER	Magnetic Tape Event Recorder
MVS	Multiple Virtual Storage
MVT	Multiprogramming system with a Variable number of Tasks
NAOS	North Atlantic Ocean Stations
NASA	National Aeronautics and Space Administration, USA
NATO	North Atlantic Treaty Organization
NAVAID	LORAN-C navigational system
NERC	Natural Environment Research Council
NESS	National Environmental Satellite Service (NOAA)
NMC	National Meteorological Centre

NMI	National Maritime Institute
NOAA	National Oceanic and Atmospheric Adminstration, USA
NORSWAM	North Sea Wave Model
NWS	National Weather Service (NOAA)
ODAS	Ocean Data Acquisition System
OECD	Organization for Economic Co-operation and Development
OSTIV	Organisation Scientifique et Technique International du Vol à Voile
OWS	Ocean Weather Ship, ocean weather station
PCK	Processor-Controlled Keying
PEE	Proof and Experimental Establishment
PFO	Principal Forecasting Office
PMP	Possible Maximum Precipitation
PRC	Progress Review Committee
PTRC	Planning and Transport Research and Computation (International) Co. Ltd
RAE	Royal Aircraft Establishment
RAF	Royal Air Force
RCA	Radio Corporation of America
RJE	Remote Job Entry
RMC	Regional Meteorological Centre
RNAS	Royal Naval Air Station
RSRE	Royal Signals and Radar Establishment
RTH	Regional Telecommunication Hub
RVR	Runway Visual Range
SATFAX	Satellite Facsimile Network
SAWS	Synoptic Automatic Weather Stations
SCODS	Standing Committee on Ocean Data Systems (NERC)
SCOR	Scientific Committee on Ocean Research (ICSU)
SCOTSTEP	Special Committee on Solar-Terrestrial Physics (ICSU)
SDB	Synoptic Data Bank
SHAPE	Supreme Headquarters Allied Powers in Europe
SR	Scanning Radiometer
SSU	Stratospheric Sounding Unit
STD	Subscriber Trunk Dialling
TSO	Time-Sharing Option
TTO	Telecommunication Technical Officer
UK	United Kingdom
UKOAA	United Kingdom Offshore Operators Association
UKWMO	United Kingdom Warning and Monitoring Organization
UNEP	United Nations Environment Program
Unesco	United Nations Educational, Scientific and Cultural Organization
URSI	International Union of Radio Science (ICSU)
USA	United States of America
VAP	Voluntary Assistance Program (WMO)
VDU	Visual Display Unit
VHRR	Very High Resolution Radiometer
VOF	Voluntary Observing Fleet

VS2	Virtual Storage System
VTPR	Vertical Temperature Profile Radiometer
WMC	World Meteorological Centre
WMO	World Meteorological Organization
WWW	World Weather Watch (WMO)

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